MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

THE GEOLOGY OF THE PERSIAN GULF AND THE ADJOINING PORTIONS OF PERSIA AND ARABIA.

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Part I.—General.

CHAPTER I.

INTRODUCTION—PREVIOUS OBSERVERS.

The present paper makes no more pretence at completeness than those of former workers in the same area. Inasmuch, however, as I have followed others, and can build upon the foundations they have laid, I may perhaps be allowed to hope that my contribution may advance us a few stages towards the thorough understanding of the geology of these interesting countries. It would indeed have been impossible for me in eight months (from November 1904 to June 1905), with no other aid than that of my own observations, to present any connected view of this large area. Further, through the difficulties, which often arose with regard to arranging for my transport either by sea or land, I was unable to avail myself fully even of that eight months.

One advantage I possess over my predecessors: whereas each one of them had to be content with seeing only a certain small part of the whole Persian Gulf region, my work has not been confined to any such limited area, and I have been able to visit personally

a portion at least of whatever they observed. In consequence I can attempt to correlate the observations of previous workers with some chance of success.

It will in fact be apparent that I have been able to form sufficiently clearly defined ideas as to the geological structure of the area, as to enable me to present the geological map of the whole region given in plate XVII. This map is of necessity imperfect, even apart from its small scale, and the boundary lines of the various formations must in no case be taken as exact. Still I do not think that there are any serious mistakes or omissions. I hope at least that it will enable the reader to form a general idea of the geology of the region as a whole, while fuller information on special areas which I have been able to survey more carefully will be found in the more detailed maps of portions of the Bakhtiyári mountains and the country between Bushehr and Persepolis represented in plates XV and XVI.

Topographical maps of the area often do not exist, while those which have been at my disposal are in all cases inadequate, and inaccurate, which makes it increasingly difficult to arrive at the correct solutions of the geological structure and quite impossible to convey the result exactly to the reader.

By far the greater portion of the area included in this memoir has hitherto never been reported on geologically, and even now large portions of what I may call the Persian Gulf region remain absolutely unknown. A complete list of all published papers containing any allusions to the geology of the region will be found on page 161. But brief mention will here be made of the more important contributions to our knowledge.

In 1856 W. K. Loftus partially surveyed and mapped the Mesopotamian plain and the Bakhtiyári mountains. His map is geologically coloured as far to the south-east as Shiraz, although it is probable that he did not personally visit the country lying to the west and north-west of Shiraz. In other portions the vast extent of country covered and the general difficulties of his work militate against any great amount of accuracy. Still his memoir has been of the

utmost value as broadly pointing out the lithological character and approximate ages of the rocks, and is in fact still our only authority on much of the country lying north-west of the head of the Persian Gulf.

In 1859 and 1860 Dr. H. G. Carter in a couple of papers in the Journal of the Asiatic Society of Bengal reported on a series of specimens collected by Commander C. G. Constable from the Persian Gulf islands and a few places on the coast. Dr. Carter's account explains quite clearly enough the nature of the rocks occurring in the various islands. There is little variety in their geological constitution; and I have relied upon his papers to enable me to trace the extension of the Hormuz series. Unfortunately in one instance at least some of Captain Constable's rock-specimens have been associated with another island than the one from which they were obtained. He describes the island of Bu Musa as containing no volcanic rocks and as dominated by a yellow limestone peak which Dr. Carter suggests may be Eocene. So far is this from being the case in the island in question that almost the whole island consists of volcanic lavas and tuffs with only an edging of later sedimentaries of Miocene age. It is impossible to say how the mistake arose; but it naturally inclines us to look with some suspicion on others of the facts stated. I have had no opportunity of ascertaining to what island rightly belong the description and specimens, which were mistaken for those of Bu Musa, and I have had no option but to accept Carter's statements with regard to all the islands that I have not been able to visit myself. In some cases these have been confirmed by independent observers, but in others I have no further information than such as I have derived from Carter's papers. In another paper on the geology of the south-east portion of Arabia Carter describes what he personally visited.

I have next to mention Dr. W. T. Blanford's two papers in 1872, in which he confirmed Dr. Carter's statements in some instances and discovered the existence of a marine formation on the Makrán coast and on some of the islands to which he gave the name of Makrán series. A few of the echinoids collected from these beds were described by

Dr. P. M. Duncan in the Palæontologia Indica, and as a result these beds were assigned to the Pliocene.

Later there is the important contribution to the geology of Persia in Blanford's book on the Zoology and Geology of Eastern Persia. In this he gives us a few more details with regard to the coast deposits at the entrance of the Gulf and on the Makrán coast, but much of his work lay outside the area to which I have been devoting my attention. At the beginning of this work is a comprehensive account of the literature relating to the geology of Persia, to which I would refer the reader for information.

I may perhaps mention the account of the Geology and Palæontology of Lake Urmi by R. T. Günther and R. B. Newton in 1899, which, although it deals with an area outside my limits, is a valuable contribution to our knowledge of the older Miocene of Persia, and also "The Geology of Armenia" by Dr. Felix Oswald in 1906, in which the author has in the most painstaking manner summarized the work of previous geologists in Armenia, besides making some original observations and conclusions of his own.

Finally I have to notice M. de Morgan's large and important Mission Scientifique en Perse, of which the Études Geologiques were published in 1905. Most of this work deals with the country to the south and south-west of the Caspian Sea.

His fossil collections, which M. Cotteau, M. Gauthier, and M. H. Douvillé have described, have been chiefly from Cretaceous rocks, and to a smaller extent from Carboniferous, Oligocene, and Eocene.

In Chapter VI M. de Morgan gives an account of the Fars beds which he saw between Hamadán and Bagdad with special reference to the bituminous deposits. No fossils were found in these beds and all M. de Morgan affirms with certainty is that they are post-Eocene. A geological map of a portion of Luristan accompanies this chapter. His magnificent collections of Cretaceous fossils have enabled him to work out in some detail the divisions of this system, of which those from aptian up to danian are represented.

A resumé of the alluvial deposits of Mesopotamia is included, taken from M. de Morgan's detailed account published in the Mém. Délég. en Perse du Ministére de l'Instr. Publ.

The only portion which M. de Morgan and I traversed in common appears to have been the Bakhtiyári country, but M. de Morgan has made no geological observations here beyond a reference to his interesting find of *Loftusia* in the Cretaceous south of Do-poulan, slightly beyond the farthest point reached by me.

Of the other contributions to the geology of the area I shall say nothing beyond referring to their mention in the appended bibliography. Some of them contain nothing but scattered references to geology by their authors who were not geologists. Some of my information has been obtained from unpublished reports. Amongst these last I may mention the brief notes left by Mr. R. D. Oldham and the late Dr. A. v. Krafft. I have had under examination the fossils collected by both of the latter on the coast of Arabia to the south-east of Muscat.

CHAPTER II.

PHYSICAL FEATURES.

The great land-locked depression occupied by the Gulf of 'Omán and the Persian Gulf includes also geologically the valleys of the Euphrates and Tigris, which within historical times have silted up their mouths to an extent that has materially altered the coast-line of this part of the Gulf, and are in the future destined to unite Hasa to Fars, just as in the past they have produced the fertile plain of Mesopotamia. This depression is bounded by mountain ranges having elevations of as much as 10,000 feet in places. These mountains sometimes run steeply down into the sea without any flat tract intervening. This is the case around the end of Ruus El Jibál and its islands, often known as the peninsula of Masandam. The same is seen at Muscat and on some of the adjoining coasts. On

the other hand there is often a flat stretch of country between the foot of the mountains and the sea, such as Al Bátinah between Muscat and Ruus El Jibál, the Trucial coast south of Ras El Khaima, and the plains behind Bushehr.

The ascent from sea level to the Persian plateau is almost everywhere accomplished by a series of sudden steps indicated by mountain ranges, and between each of these lies a more or less broad alluvial plain. These mountain ranges run in an extraordinarily constant north-west and south-east direction as far as the Straits of Hormuz, where they meet the semicircular arc to which belong the mountain chains of Baluchistan and Sind. The mountains of 'Omán run in lines quite parallel to the latter arc.

It is difficult, owing to lack of soundings, to attempt any detailed description of the nature of the contours of the sea-floor in the Persian Gulf area; where the mountains directly adjoin the sea, the water is naturally very deep; this is to be seen at Masandam peninsula and within its long narrow inlets. After going down suddenly into some 60 fathoms of water, the sea-bottom is flat or undulating for a distance of 50 miles from Masandam; then comes a sudden drop and we are in water of 150 fathoms. Thus a wide shelf is formed between the true base of the mountains and the top of a great sea-cliff. This sea-cliff can be traced right along the Makrán coast in the one direction, and along the Bátinah coast in the other, where it is much nearer the present land, leading one to look upon Al Bátinah as an unsunken portion of the same shelf.

The sea-bottom of the Persian Gulf proper, outside the areas affected by recent coral reefs or deltaic deposits, is flat or gently undulating. Rising here and there above its general level are various isolated eminences, which manifest themselves in the numerous islands dotting the expanse of the Gulf. The whole forms a rather more elevated portion of the same terrace, which we have seen is terminated by a sub-marine cliff in the Gulf of 'Omán. These islands are the following, going towards the west,—The Quoins and Masandam island, Hormuz, Lárak, Qishm, Henjám, the Greater and the Lesser

Tunb, Bu Musa, Farúr, Sirri, Sir Bu Nu'air, Qais, Hindarábi, Shaikh Shuaib, Zirkoh, Dás, Qarnein, Yás, Arzanah, Hálúl, Daiyinah, Dalmah, Shurá 'Awah, the Bahrain islands, Khárag, Farsi, 'Arabi, Qran, Herguz, Qáru, Kubbar. This list does not include low-lying reefs, or shoals uncovered at high water. These are found in many places in the Gulf, but particularly in the Pearl-Fishing areas—round Bahrain and between Qatar and the Trucial coast.

CHAPTER III.

GEOLOGICAL FORMATIONS.

The geological formations which have been noticed in the Persian Gulf area are the following, in descending order:—

Shelly conglomerates and dead coral reefs of the littoral; red sandhills of the coast of Trucial 'Omán; alluvium of Mesopotamia; river and lake deposits of 'Omán and the interior of Persia.	Recent or sub-recent.
Foraminiferal Oolite or "Miliolite" .	Pleistocene.
Bakhtiyári series, grits and conglomerates	Pliocene.
Freshwater beds of Sur, 'Omán . .	Pliocene?
Fars series, marls, clays and sandstones with limestones and interbedded strata of rock-gypsum	Miocene (Helvetian-Messinian).
Urmi series, limestones . . .	Miocene (Burdigalian).
Nummulitic limestone of Khamir . .	Oligocene (Stampian).
Nummulitic limestone of Persia, Muscat series, and Bahrain series . . .	Eocene (Lutetian).
Hormuz series, lavas and tuffs with interbedded clays and sandstones .	Upper Cretaceous or Lower Eocene.
Hippuritic limestones of Persia and 'Omán	Upper Cretaceous.
Serpentinous and other igneous rocks of 'Omán	Jurassic or Lower Cretaceous.
'Omán series, limestones and slates with beds of chert	Carboniferous to Trias.
Hatát series, schists and quartzites .	Archæan?

1. Hatát Series.

The beds of this series are undoubtedly older than the oldest fossiliferous rocks met with in 'Omán. The earth movements of the Mesozoic era have, however, folded them in amongst the later deposited 'Omán series, so that it is in some places difficult to indicate where the line of division comes, especially as certain beds in the 'Omán series have through pressure acquired a fissility that causes them to mimic a schistose structure, which they do not possess. The later sedimentaries are also, like the Hatát series, penetrated by quartz veins, which have been severely crushed, and have been intruded by the basic igneous sills of Jurassic or Lower Cretaceous age. Here and there, however (page 95), there is evidence of considerable unconformity between the Hatát series and the 'Omán limestones. Moreover, they chiefly occur in isolated areas, where it seems clear that they have been laid bare by the removal of the limestones of the 'Omán series, which once overlay them completely.

They are truly metamorphic rocks, which cannot be said of the 'Omán series. They consist of mica schists, talc schists, chlorite schists, hornblende schists, quartz schists, calc schists, and quartzites. They bear a general resemblance to the rocks of the Dharwar series in Peninsular India, and for this reason I provisionally propose to regard them as Archæan in age. They are penetrated by great masses of quartz which are evidently of ancient origin at all events previous to the great crushing stresses, which have deformed, foliated, and metamorphosed quartz veins and sedimentaries alike.

They occur in plains outcropping in ridge after ridge of insignificant elevation and showing a uniform direction of cleavage for great distances. The largest of these plains is that of the Saih Hatát, some 20 miles long by 10 broad. (See page 93.)

On the edge of the great Samáil valley, north of Nafa'a, quartzites and schists lie in juxtaposition both to the 'Omán limestones and to the serpentinous series. Near Ruwi, 4 miles from the sea at Matra and in the Wadi Adi schists crop out irregularly amid the Carbo-Trias

rocks, while a note of the late Dr. A. v. Krafft refers to a series of schists and quartzites underlying the Cretaceous rocks near Sur.

These are the only localities in which I can confidently assert that the Hatát series is exposed.

2. 'Omán Series.

Under this name it will be convenient to describe the whole series of sedimentary rocks of which the great mountain range of 'Omán, known throughout much of its length as Jebel Akhthár, consists, with the exception of the extremely metamorphosed and schistose rocks, which, both from their occurring in areas clearly defined from the others, as well as on account of their greater degree of alteration, can be separated from the 'Omán series and are probably to be placed in the Archæan group of strata.

However, even after we have thus separated off a portion of the 'Omán rocks, when we come to consider the age of the remainder we find that they extend over a period ranging at least from the Permo-Carboniferous to the Trias, with a possibility of their including rocks of both earlier and later dates. The reason of this uncertainty is that the almost complete absence of fossils and the intensely disturbed condition of the strata, added to the similarity which the various beds exhibit in their lithological character, render it most difficult to determine the relations between different parts of the series. I have no doubt, however, that a more detailed and extended survey of the country than I was able to perform would completely elucidate their geological structure and clear up our present difficulties.

The rocks consist for the most part of limestones, which are generally very siliceous: some of these limestones are quite massive and do not appear to have undergone any particular crushing; these vary in colour from a dark blue, almost black, to a pale grey, often with a distinctly reddish tinge. It is in these limestones alone that any fossils have been found, although even in these they are exceedingly rare, and the remains of organisms generally appear as mere shapeless, siliceous iron-nodules. Other limestones are often extremely fissile and show evidence of having been severely folded and

crushed. Limestones of this type are often found in juxtaposition to the massive limestones without any noticeable unconformity. Interbedded are thin layers of shale, slate, and sandstone; the latter has frequently taken on the appearance of quartzite. Besides these are beds of a red and grey jasper as much as ten feet in thickness; this altered condition of what were undoubtedly ordinary sediments at one time, is probably to be ascribed to replacement of the original material by silica from an external source.

As has been said, this series extends throughout 'Omán, forming the backbone of the great mountain range, which runs in a general south-east and north-west direction from Jebel Jaalan at the Ras El Hadd corner of Arabia to the base of the Masandam peninsula. It approaches the sea to within a distance varying from five to ten miles, the intervening country being filled up either by the igneous rocks at Muscat or by the later deposits of Cretaceous, Eocene, or Sub-Recent age. The range runs the entire length of the Masandam peninsula, on the eastern side of which the rocks of the 'Omán series dip directly into the sea and also on the western side, almost as far as Ras El Khaima. For the remainder of the Trucial coast they are overlain by later deposits. It seems probable that some very much contorted flaky limestones, which I met with on the Persian coast at Hamairan opposite the island of Qishm and at Bostánah, also belong to this series. At the latter place they are associated with red, slightly porcellanous shales resembling some of the beds seen in this series at Muscat. They seem to have formed a very irregular floor, on which the shallow water sediments, lavas, and tuffs of the Hormuz series were laid down or poured out.

Certain limestones, which have a very high dip and are much folded and contorted, occur as rocky islets near the small island of Daiyinah. These probably are of the same age. They are here unconformably overlain by sub-recent conglomerates and "miliolite."

I found fossils in two bands of siliceous limestone in the Wadi Adi some six miles south-west of Muscat. One of these was of the black compact variety and contained corals, probably allied to

Cyathophyllum,[1] and silicified brachiopods. The other was of a paler colour tinged with red containing numerous specimens of *Productus* cf. *indicus*, *Spirigerella*, *Dielasma*, *Camarophoria*, *Athyris*, *Orthothetes*, *Streptorhyncus*, with *Orthoceras* and encrinites. Interbedded are some thin layers of a yellow slaty shale containing *Bryozoa* probably belonging to the genera *Aulopora*, *Fistulipora*, *Protoretopora*, and *Fenestella*, and a coral resembling *Michelinia*. These fossils are indicative of a Carboniferous age, corresponding perhaps to the middle Productus Limestone of the Salt Range. I found traces of corals at the foot of Jebel Nakhl near Samáil, some 50 miles from Muscat, and others of a similar type in the Masandam peninsula between Dibah and Ras El Khaima.

Dr. Blanford found fossils in rocks in Elphinstone inlet, which undoubtedly include the black limestone which is characteristic of the series. There are numerous specimens of a *Myophoria* which is almost certainly of a Triassic type: a species of *Exogyra* may also be of the same age, but it belongs to a type which hitherto has not been found in strata earlier than Jurassic.

Dr. Diener has been kind enough to examine the Elphinstone inlet specimens and to confirm the above determinations.

3. Basic Igneous Series of 'Omán.

These rocks have been described several times over, at least that particular type of them which is represented by the big outcrop at Muscat. Amongst those who have mentioned them may be cited Carter (3) and Blanford (8), by whom they were regarded as belonging to the ancient crystalline series. It is evident, however, that they are of later date than the 'Omán series as I have abundant proof of their having been intruded into the latter, which they have sometimes altered slightly. They are largely of plutonic origin, and seem to have been injected in the form of enormous sills. The bedding in those places where it can be distinguished is perfectly conformable to that of the 'Omán series, and the two series evidently underwent their folding at the same time. It is possible that portions of the series

[1] Prof. Diener has identified these as a species of *Lonsdaleia*. See also p. 92.

may have been sub-aërial flows. There seems no reason why the serpentinous rocks should not have been surface lava flows. In any case the thicknesses attained by the beds of igneous material are immense, though it is impossible to say how great, as we do not know whether one or many folds are represented in a single outcrop.

Assuming that the outcrop at Muscat is a single fold having a uniform dip of 45°, then the thickness of the bed must be some 4,000 feet. They occupy a large area on both sides of the Wadi Samáil, where they rest against the foot of Jebel Nakhl on the north-west and Jebel Tyin on the south-east. I did not reach their limits in my journey up the Wadi Samáil to the south-west. It seems likely from Miles' (29, page 522) observations that the range of Jebel Hallowi, which merges into the Arabian desert on the south, consists of rocks of the same series. In the peninsula of Masandam a considerable outcrop of them is met with, extending from Khor Fakkán to Dibah and then from the other side of the alluvial plain at Dibah, across to the western side of the peninsula. It seems possible that an isolated hill of hornblende diorite in the island of Henjám is an inlier of the same age. It does not resemble any of the Hormuz volcanic rocks which I have seen, although I have met with the latter over widely spread areas. It is not unlikely there were high standing patches above the floor on which the Hormuz lavas and sediments were deposited. Denudation has since removed the Hormuz rocks which covered them, and Fars sediments were in their turn deposited. The denudation which has subsequently acted on the area has left these older patches as inliers amid the Fars series.

It is also fairly certain that certain volcanic rocks underlying the Hormuz beds at Al Buza, near Lingah, are to be assigned to this series.

These rocks are for the most part basic in character. They include diabase, diorite, gabbro, and dolerite. They have been largely altered into epidiorites and serpentine. The dark greenish cliffs of Muscat for the most part consist of the latter, the joints being filled up with a decomposition product, which is mostly magnesite. This is

by far the most widely spread type of rock, and all the others' wherever met with seem gradually to merge into it. Besides the large outcrops, whose connection with a more deep-seated mass has not been verified, I have also come across many small intrusions of both serpentine and diabase between the bedding planes of the 'Omán series. In these instances the limestone, both above and below the intrusion, has been rendered quite crystalline by the contact. Intrusions have also taken place into the Archæan rocks of the Hatát series. Although these are generally of a basic character, yet A. v. Krafft has found some granitic intrusions near Sur which I gather that he considered to be of the same age as the others.

Their dip seems to be invariably conformable to that of the 'Omán series, and as there is occasionally evidence that the igneous rocks have been severely crushed it seems that one may conclude that subsequent to, and possibly as a result of, the eruption of this great volcanic mass, the folding and upheaval of both the igneous and the sedimentary rocks of the 'Omán mountains took place simultaneously.

They are overlain with complete unconformity, not only by the Nummulitics at Muscat, but also, as would seem from von Krafft's observations, by the Upper Cretaceous series between Muscat and Sur.

Since their age must at least be post-Triassic, it seems likely that it will be found that the outbreaks occurred at the end of Jurassic times. This would be earlier than the great Deccan Trap flows of India.

4. Cretaceous.

Cretaceous rocks are fairly widely spread through the area comprehended in the present memoir, but in particular they occur in two zones or portions of that area. The one of these runs as a broad belt in a general north-west to south-east direction through the centre of the Persian plateau. The other is the south-eastern corner of 'Omán, and it is from Carter's (9) observations that we know that rocks of this age are to be found at several places all along the coast going south-west towards Hadramaut, far beyond the limits of the map in plate 17.

As is evident from the map, in no case did I get beyond the northern limits of the Hippuritic limestone of Persia. It presents remarkably constant lithological characters and is very compact and often slightly crystalline, exceedingly massive, showing the bedding planes with difficulty in the places where I examined it,—north of Shiraz in the Marv Dasht, and in the Bakhtiyári country. It seemed to be generally devoid of fossils, except fragments of *Hippuritidæ*.

M. de Morgan, however, has made large collections of fossils from various Cretaceous localities, and the examination of these by MM. Cotteau and Douvillé has shown that the Hippuritic limestone of Persia extends from the aptian to the danian.

Among the limestones I saw at least one thick bed of bluish shales some 250 feet, and it is possible that there may be others. There has certainly been a considerable amount of disturbance and denudation of the series before the deposition of the Nummulitics upon them. As we shall see (pages 18 and 84) that in this part of Persia the lowest Nummulitic beds are not older than the Khirthar or middle lutetian, there would have been ample time for considerable changes to occur in the land surface, and of this there is abundant evidence.

At Khamir near Bandar Abbás an inlier of Hippuritic limestone occurs. Here I found *Exogyra matheroni* D'Orb. and *Radiolites* sp. It is therefore probably of senonian age.

The Cretaceous rocks at Ras Fartak and Ras Gharwên in the south-eastern part of 'Omán are probably cenomanian. Professor Duncan (17) found the following species of echinoids amongst Carter's specimens:—

Cidaris cenomanensis Cott.
Pseudodiadema roemeri Desor.
Tetragramma depressum Roemer.
Salenia scutigera Gray.
Cidaris scutigera Münst.
Salenia personata Defr.
Salenia scripta Agass.
Salenia petalifera Bronn.

Holectypus cenomanensis Guér.
Holectypus planatus Roemer.
Pygaster truncatus Agass.
Epiaster distinctus Agass.
Hemiaster similis D'Orb.
Cottaldia carteri Duncan.

Near Kalhát A. v. Krafft found a great development of limestones. Amongst the fossils which I have seen in his collections the following occur from this locality :—

Radiolites sp.
Pyrina sp.
Terebratula sp.

These rocks apparently belong to the Upper Cretaceous. Plate IX shows these limestones at Kalhát overlain by sub-recent conglomerates. According to A. v. Krafft these Cretaceous rocks pass up into Nummulitics, which are of Laki age, and probably in places rest unconformably on the basic serpentinous series. There is also a possibility that a limestone underlying the Nummulitic pebble bed at Darzeit is also of this age (page 89).

It seems likely, therefore, considering the wide distribution of Upper Cretaceous limestones in the area, that the sea at this period extended over the whole of Southern Persia, and as far as the south-eastern corner of 'Omán, washing the shores of a land composed of the Carbo-Triassic and basic igneous rocks of 'Omán.

5. Hormuz Series.

Of later date than the Hippuritic limestone, are the beds here classed. They are intimately associated with the Hippuritic limestone at Khamir on the Persian coast between Bandar Abbás and Lingah, where portions of the red gypsum bed with hæmatite are found penetrating the Hippuritic limestone, as a continuation of an outcrop of the same rock occurring with lava flows. The lava flows were poured out on a Cretaceous surface, but it is not unlikely that some of them were submarine, as they are interbedded perfectly evenly with beds of sedimentary origin. At Khamir Eocene rocks are exposed as well

as the Hippuritic and Hormuz series, the two latter occurring as inliers within deep bays of the Nummulitic cliffs, which here are sandstones with thin-bedded limestones. Since we know that the lowest beds of the Nummulitics are probably no older than the Khirthar series, the age of these Hormuz rocks may be anything between the Upper Cretaceous and the Middle Eocene.

The eastern limit of these beds seems to be the latitude of the island of Hormuz, and I have observed them on the Persian coast as far west as the island of Shaik Shuaib. They occur on almost all the Gulf islands as far west as the peninsula of Qatar, but whether they exist either on the mainland of Qatar, or on the coast of Arabia to the south and east of Qatar, is not known. I myself did not find them on the Pirate coast.

They appear to have existed as a continuous tract of land in Eocene times, separating the Nummulitic areas of Bahrain and Persia. This land may have been depressed to some extent during Miocene times, but subsequent elevation and exposure to aërial denudation produced the irregularly hilly country, which the widespread subsidence of comparatively recent times has left in the form of islands. The volcanic rocks of the series consist of rhyolites, trachytes, ash beds, and tuffs. In the island of Hormuz sedimentary rocks are very poorly represented as far as can be seen; here and there gritty sandstones, shales and carbonaceous limestones are visible amid the vast beds of rock salt and gypsum. In Hormuz the rock salt makes up as much as half the entire formation. It presents very much the appearance of being eruptive. It is associated with hæmatite, iron pyrites, sulphur, dolomite, and anhydrite. Owing to the subsequent solution of the salt the surface of the ground has fallen in, giving the hills occupied by the Hormuz series a singularly craggy aspect. Their almost entire barrenness increases the peculiarity of their appearance. In some localities salt is practically absent, as for example in the island of Bu Musa, where its place is taken by gypsum. Both gypsum and salt beds are of variegated colours, in which red predominates, due to the presence of red iron oxide (red ochre), which

has arisen from the decomposition of the hæmatite. Large deposits of this exist, which have been profitably worked. The general appearance and vivid colouring of the country consisting of rocks belonging to this series make it easy to recognize from a distance.

At Bostánah and Hamairan on the mainland of Persia near Lingah sedimentary rocks are more largely developed than in Hormuz. At these places thick beds of a pink sandstone are the prevailing type. Interbedded with them are trachytes, ash beds, and gypsum. At both Khamir and Bostánah a rhyolite occurs, which is in a very decomposed condition. Included within it are fragments of limestone, presumably Cretaceous, as it rests on Hippuritic beds, and the whole mass is permeated by sulphur, which has at various times been commercially worked.

In addition to the rocks which have already been mentioned as occurring in the Hormuz series, there are also beds of chert or jasper. A glistening white rock of this nature crops out in two high peaks in the island of Hormuz. These have been thought by many persons to consist of salt, no doubt on account of their proximity to such large masses of salt as exist in Hormuz. The jasper is more or less decomposed. Similar beds are found in nearly all the islands on which this series is found. In Henjám there is an outcrop of a cherty rock having a cellular structure, the cavities of which contain the partially decomposed remains of what evidently was once a volcanic rock. In the portions of the outcrop which have been exposed to the weather this softer volcanic stuff has been removed, leaving the secondary quartz, which has been hard enough to withstand the weather, with its chambers empty.

6. Eocene.

Rocks of this age occur in three distinct areas, in each of which the lithological facies is different, which seems to mark them off as separate areas of deposition. These three areas are—

1. Persia.
2. 'Omán.
3. Bahrain.

1. *Persia.*—A great series of more or less massive limestones, with interbedded shales and sandstones, extends through the whole of Persia, resting on rocks of Cretaceous age,—either Hippuritic limestone or the volcancis of the Gulf region. Except nummulites the formation, where I saw it, was generally devoid of fossils, or at all events of fossils in an identifiable condition. The nummulites even are not particularly numerous except in certain beds, and are often not in a matrix from which they can be conveniently extracted for purposes of identification. Systematic search for nummulites and careful observation of the stratigraphical relations would no doubt throw considerable light on the precise age of different portions of this limestone *massif*, and even enable us to map geologically the country over which it extends, but during my rapid traverses I was unable to accomplish anything of the kind.

The most complete section I saw of these beds was in the Bakhtiyári mountains on the Ahwaz-Ispahán road between Dehdiz and the bridge over the river at Shalil. Here some 6,000 feet of the series are exposed, resting on a thick bed of bluish shales which Loftus considers to be Cretaceous; beneath this is Hippuritic limestone. There is no unconformity to be detected in this section between the Cretaceous and the Nummulitics; they are both tilted at an angle of from 30° to 50°, but seeing that in other places, where I observed a junction between the two, the shale bed is not always present, there must evidently have been erosion of the Cretaceous before the Nummulitics were deposited. Moreover, the lowest beds of this section are characterized by an abundance of *Nummulites lævigatus*, which implies that they correspond in age to the uppermost beds of the Lower Khirthar of Baluchistan and Sind, or perhaps even to the Upper Khirthar according to Vredenburg's[1] views on the zonal distribution of the Indian nummulites.

The Nummulitic rocks at Shalil cannot therefore be older than middle lutetian.

[1] E. Vredenburg: *Rec. Geol. Surv. Ind.*, XXXIV, p. 87, 1906.
For the identification of this as well as of the other nummulites collected by me in Persia and Arabia, I am indebted to Mr. E. Vredenburg's kindness.

It seems likely that portions at least of the Nummulitic limestone of Persia may be older than this, as I found amongst the specimens collected by W. K. Loftus from Kirrind on the Turko-Persian frontier and now preserved in the British Museum echinoids whose identity with *Arachniopleurus reticulatus* D. & S. is hardly doubtful. This species has been shown by Mr. E. Vredenburg to characterize beds of Laki age in India; which correspond to lower lutetian in Europe. No beds of the age of the Ranikot have been definitely shown to exist in any part of Persia, and it is quite possible that this stage is really absent.

Lithologically the massive limestones are hardly distinguishable in character from the Hippuritic limestone; perhaps the latter is more crystalline, and it certainly as a general rule is more massive and shows the bedding less plainly. Often an alternation of harder and softer beds in the Nummulitics enables the bedding to be made out easily.

A reference to the map (Plate XVII) will show the distribution of the Eocene beds in Southern Persia, as far as I was able to make it out.

2. *'Omán.*—In 'Omán rocks of Nummulitic age are exposed on the coast to the west and south-east of Muscat. Here they rest unconformably on the upturned and denuded edges both of the serpentinous rocks as well as of the Carbo-Triassic series of 'Omán.

At the base occurs a pebble bed, which in some places is developed to a thickness of as much as 40 feet, and in others thins off to 4 or 5 feet only, being interbedded with variegated bands of gypsiferous clay or of highly ferruginous sandstone of small thickness. The pebbles consist of the dark blue Carboniferous limestone, of quartz or chert derived either from the Archæans or from the metamorphosed beds of the 'Omán series, and occasionally of the basic igneous rock of the neighbourhood. This pebble bed passes up into a yellow rather sandy limestone, containing nummulites, numerous casts of mollusca, and echinoderms. Near Muscat at Darzeit and at Bandar Jissa a thickness of some 200 feet is exposed.

The nummulites found here are *N. atacica* Leym., *N. globulus*, *Assilina granulosa*, and *Assilina Leymerii*. These are accompanied

by species of *Diplopora, Schizaster, Moira,* and *Echinolampas,* and by *Prenaster* sp. *aff. oviformis* D. &. S., while Mr. R. B. Newton has recorded a species of *Campanile* from the same locality.[1]

These beds are therefore clearly of Laki age, or lower lutetian. They are seen to rest on lateritic bands, pointing to a more or less prolonged period of continental conditions. The significance of these lateritic bands has been pointed out by Mr. E. Vredenburg[2] in the case of Baluchistan.

Farther along the coast to the south-east, it appears from the observations of von Krafft that this Nummulitic series rests on Upper Cretaceous rocks, at the base of which von Krafft found hippurites.

At Mislook, 8 miles inland from the latter locality, is a conglomerate bearing considerable resemblance to that of Darzeit, only crowded with numerous specimens of *Nummulites lævigatus* Lam., *N. acutus* Sow., *N. scaber* D'A. & H., and *N. gizehensis* var. *Lyelli,* which is also of Upper Eocene age. In beds of the same series R. D. Oldham found *Velates schmideliana,* with species of *Linthia.*

The Eocene beds of this locality are therefore of the age of the passage beds between the Lower and Upper Khirthar.

3. *Bahrain.*—Here we encounter a facies of the Eocene, which is quite different from that of the other two areas. A thickness of some 500 feet of strata is exposed, and neither the top nor the bottom of the series is visible. The rocks are for the most part either limestone or a white marl. They are characterized by the extraordinary amount of siliceous matter scattered through the series, either in the form of layers of flint or cherty concretions or quartz geodes. In this respect they would seem to be a continuation of the strata which Doughty (26) describes in Nejd as giving rise to plains strewn with flints.

Nummulites are most abundant in the middle of the series, where *N. gizehensis* var. and *N. lævigatus* var. are found in a white sandy

[1] R. B. Newton : Tertiary fossils of Somaliland, *Q. J. G. S.,* LXI, p. 155, 1905.

[2] *Rec. Geol. Surv. Ind.,* XXXIV, p. 179.

limestone underlying more compact limestones with flints. Above these is a saliferous marl with calcareous concretions passing up into regular limestone.

The following fossils have been found in these beds :—

Nummulites beaumonti D'A.
Nummulites lævigatus Lam. var.
Porocidaris schmidelii Münst.
Schizaster mokattamensis P. deLoriol.
Echinolampas n. sp.
Echinolampas sp.
Cidaris sp.
Ostrea elegans var. *exogyroides* Mayer-Eymer.
Chama latecostata Bellard.
Chama sp.
Spondylus ægyptiacus Newton.
Pecten sp.
Terebellum sp.

The Nummulitic beds pass down into a dazzling white chalky clay containing quartz concretions and so through more sandy beds permeated by salt and gypsum into the limestone of which Jebel Dukhán consists. This is compact, with cherty concretions in places, and with intercalated softer layers of a sandy clay, and contains a few nummulites and numerous mollusca and corals in a poor state of preservation. The fossils suggest an age for the Bahrain series contemporaneous with the Mokattam stage of the Cairo beds, which probably correspond to the priabonian stage of the Middle Eocene.

It seems probable that this area of deposition was separated from the other two, not only by the great Carbo-Trias mountain chain striking south-east to north-west, but also by the area occupied by the lavas and ash beds, with their associated sediments belonging to the Hormuz series. It seems likely that this land barrier was not completely removed until post-Pliocene times.

7. Oligocene (Stampian and Aquitanian).

The only locality in Southern Persia where the presence of rocks of Oligocene age is clearly established is at Khamir, on the coast halfway between Bandar Abbás and Lingah (see page 102 and the map in plate XI). Here the tall cliffs consist of sandstones with intercalated bands of thinly bedded marl or argillaceous limestone containing flints. The limestone bands become more frequent lower down until at the base there are only flaky or rubbly limestones resting unconformably on the Hormuz series. These limestones contain *Nummulites intermedius* in abundance and are therefore stampian in age corresponding to the Lower Nari. The Fars gypsum beds rest upon the eroded surface of these Lower Nari limestones, the difference in dip between the two series not being great, the Fars beds dipping 35° S. W. and the Oligocenes 40° to 50° S. W. (see page 105). The upper sandstones are perhaps to be assigned to the Upper Nari and are aquitanian in age.

Mention may here be made of a well-preserved specimen of a fish which came from a compact limestone near Shushtar on the Kárún river in Arabistán, and to which Dr. A. Smith Woodward [1] has given the name *Isurichthys orientalis* and considers to be Oligocene in age.

It is probable that the bed in which this occurs forms part of an outcrop which was mapped by W. K. Loftus as Nummulitic.

8. Urmi Series.

I have taken this name from the well-known locality in Armenia where rocks of this age are so extensively developed and where their sequence has been fully worked out by Abich and R. B. Newton. The localities in Southern Persia where I can actually assert that these beds are found are confined to two, one mentioned by W. K. Loftus near Kirrind, from which I have seen and carefully examined the fossils which that indefatigable worker collected, and one discovered by myself at Shalil, in the Bakhtiyári mountains. From the former locality I have identified *Pecten urmiensis* Abich,

[1] Catalogue of Fossil fishes in the British Museum, IV, 1901, p. 453.

Pecten prædubius Abich, and *Ostrea* sp. *aff. multicostata* of the lowermost gypsum beds, and of the Indian Gaj series, so long referred to in the publications of the Geological Survey of India as *Ostrea multicostata* and *Clementia* sp. *cf. non scripta* D'A. They are also closely adjacent to the Eocene limestones, and in fact these fossils were labelled by Loftus as Nummulitic. The position of the bed is, however, precisely that of the locality at Shalil, occurring immediately between the middle lutetian limestones and the lowermost gypsum beds of the Fars series.

At Shalil *Operculina complanata* occurs with *Pecten cf. rotundatus* Lam. and *Clypeaster* sp. *aff. depressus* Sow., and the unconformity above and below is proved beyond a doubt (see page 30). A similar unconformity exists in the case of the beds at Lake Urmi, and quite apart from any question as to their actual age their claim to be considered by themselves is, I think, justified. I am not, however, inclined to think that the unconformity between the Urmi series and the Fars beds was great or existed everywhere, firstly, because I gather that there is often no stratigraphical evidence of such, and, secondly, because there is no marked change in the character of the fauna. *Ostrea* sp. *aff. multicostata* appears to have existed in Urmi times, and *Ostrea verleti* is found in the upper limestones of Lake Urmi, while it still remains as the characteristic fossil of most of the Fars beds.

The actual state of the case probably is that prior to the period of gypsum formation there was a widespread submergence so that the basal beds of the Fars series often rest on Oligocene or Eocene strata, which were dry land while the Urmi beds were being deposited. But in some localities where the Urmi beds existed deposition simply continued uninterruptedly. It has been stated unreservedly by certain geologists, of whom Mr. Felix Oswald (40, page) is the most recent, that the gypsiferous period was one of elevation and separation of the sea into lagoons. But I consider that submergence and extension of the marine area first took place and that elevation was quite subsequent (see also page 29). It is unlikely that any portions of the Urmi beds were elevated into dry land before Fars times.

As to the age of these beds, Mr. Felix Oswald (40, page) has stated that they are at the oldest helvetian in age. I will briefly state my reasons for regarding them as burdigalian. These are mainly based on the age which I have assigned to the basal gypsum beds of the Fars series. On page 30 and following I have pointed out that these basal gypsum beds must be approximately contemporaneous with the Gaj series of India and cannot be newer than helvetian. This gives a burdigalian age for the Urmi beds.

As far as internal evidence goes an examination of the fossils described by Abich and R. B. Newton will show that most of these which have been identified with European forms are found in burdigalian as well as helvetian strata, the one exception being *Ostrea verleti* Desh. occurring in the topmost beds. This has hitherto been only found in beds of tortonian age, so that the assumption of a burdigalian age for these beds will immensely extend its range. It is, however, noteworthy that Mr. E. Vredenburg has found *Ostrea verleti* in Baluchistan in beds which are recorded by him to contain Gaj fossils[1] while *O. peguensis* Noetling of the Lower Miocene of Burma is probably a variety of the same widespread and very variable species. It is also worthy of note that accompanying *O. verleti* in the uppermost beds at Lake Urmi is *Thamnarea polymorpha* of which Mr. Gregory remarks that the genus has not hitherto been known in rocks of Miocene age. The table on page 25 will show the correlation of the beds from Sind, Baluchistan, Persia, and Armenia, as I understand it.

Lithologically these beds are impure limestones, generally reddish or fawn coloured. It is not improbable that in many other places than the two mentioned certain limestones in contact with the Fars gypsum beds, which have been mapped as Fars, actually belong here, but further careful examination and search for fossils is needed to settle the point. Such localities in particular occur near Chinar Rahdar (page 73), north-west of Kázrun (page 69), and at Birkah Siflah (page 108).

[1] *Rec. Geol. Surv. Ind.*, XXXIV , p. 92.

Correlation of Oligocene and Miocene beds in Western Asia.

	Sind.	*Baluchistan.*	*Southern Persia.*	*Persian plateau.*	*Armenia.*
Messinian and Pontian.	Lower Siwaliks vertebrate fauna.	Gwadar beds with *Pecten vasseli*. Nodular beds of Ormara.	Deposits in Qishm, Henjam, and Kharag Is., etc.	Freshwater sandstones and conglomerates of Bakhtiyâri series.	Sandstones and conglomerates. Maragha bone deposits.
Sarmatian.			Fars series. Marls, clays, and sandstones with *Ostrea verleti, Venus aglauræ, Astarte hyderabadensis, Echinolampas jacquemontii.*		
Tortonian.				*Ostrea verleti* beds. Fars series.	
Helvetian.		*Ostrea verleti* and Gaj mollusca.	Gypsum beds with *Ostrea sp. aff. multicostata.*	Gypsum beds.	Gypsum beds.
Burdigalian.	Gaj series. *Ostrea sp. aff. multicostata, Clypeaster depressus* and *Venus aglauræ.*		Limestones of Kirrind with *Ostrea sp. aff. multicostata, Pecten urmiensis,* and *Pecten prædubius.*	Limestones with *Clypeaster sp. aff. depressus, Pecten rotundatus,* and *Operculina complanata.*	Urmi beds with *O. verleti, Venus aglauræ, Pecten rotundatus, Pecten beudanti.*
Aquitanian.	Bugti beds. *Anthracotherium sp. aff. magnum.* Upper Nari.				
Stampian.	Lower Nari.		Limestones of Khamir with *N. intermedius.*		
Tongrian.					
Eocene.	Khirthar Series.		Beds of Lutetian age.		

N.B.—In this table thick lines indicate unconformities.

9. Fars Series.

This is by far the most important and widely spread formation in Southern Persia and the Gulf region. Various portions of it have been noticed and described by more than one geologist. As each observer has written with insufficient knowledge of the series as a whole, and often with very inadequate material from the portion which he actually saw, the result has been some confusion in the nomenclature of the beds.

In the preliminary account of the Persian Gulf geology published in Mr. T. H. Holland's General Report for 1905, it was proposed to extend Blanford's name of Makrán series to the whole; but seeing that that term is now associated solely with beds which have been regarded as Pliocene and possesses to some extent a significance parallel to that of the great Indian Tertiary groups, such as Ranikot, Khirthar, Nari, Gaj, I have thought it unwise to extend it to cover rocks whose ages date back to the Lower Miocene.

Loftus' name of "Gypsiferous series," apart from its inappropriateness in a region where gypsiferous formations of various ages are met with, must be rejected because he has included in it the Bakhtiyári gravel series which are very distinctly unconformable to the beds I am now describing. On the other hand it seems clearly necessary to take due cognizance of the fact that we are dealing with beds which form an intimate stratigraphical association. This precludes the idea of disconnecting them either by giving more than a secondary importance to lithological or palæontological divisions, or by an attempt to describe them in accordance with recognized European divisions. Moreover, it would be impossible to fix any definite boundary lines based on palæontological considerations. It must, however, be remarked that Mr. E. Vredenburg[1] has proposed to extend the name Makrán series to cover everything newer than Khirthar and older than Manchhar. He has been led to this by the discovery in Baluchistan of a continuous series of deposits, whose lowest members

[1] E. Vredenburg Zonal distribution of Indian Nummulites, *Rec. Geol. Surv. Ind.*, XXXVI, p. 89.

contain fossils of Nari age, while its highest beds are identical with the *Pecten vasseli* or coast division of my Fars series. This series is undoubtedly parallel with the beds which I am now describing, and differs from it only by the absence of a definite period of gypsum formation and the fact that in Persia the submergence must have taken place much later since the oldest part of the Fars series contains only such fossils as are characteristic of the Gaj series. As I have remarked above, it seems unwise to extend the application of a name which has hitherto been well known in a restricted sense. Moreover, if a single name must be made to include all the beds of this age, even the Miocene of Burma according to Mr. Vredenburg, there is no reason to withhold it from beds as far west as the Dardanelles, which will no doubt be found in great measure to have been sediments in the same great basin of deposit as Baluchistan.

For these reasons I have decided to adopt the name Fars series for the whole, after the important province of that name in Persia where they are so largely developed, and to content myself with making three divisions which seem on the whole to be justified and will be convenient to make use of in my descriptions. The total thickness attained by the series as a whole cannot be less than 17,000 feet.

These divisions are in ascending order—

1. Basal gypsum beds.
2. Plateau beds or *Ostrea verleti* beds.
3. Coast beds or *Pecten vasseli* beds.

1. *Basal gypsum beds.*—At the base of the Fars series are rocks which are characterized by the large amount of rock gypsum which they contain. Gypsum certainly is found more or less throughout the series, but for the most part in both the Plateau beds and the Coast beds it occurs chiefly as veins and is of secondary origin. But in this division it exists in beds often as much as 10 feet thick, which are evidently contemporaneous with the impure sandy limestones, shales, and clays interbedded with them. So dominant a feature are the beds of gypsum, however, that one often has the impression of traversing hills entirely made up of gypsum. This is partially due to

the fact that these soft beds are considerably folded, and within a very short distance the same beds of gypsum may be many times repeated. This I have often noticed in the many different places where I have seen these beds exposed, and this circumstance renders any calculation of their thickness little more than a mere guess. I should say, however, that this portion of the Fars series must be at least 1,000 feet thick.

These basal beds present a very characteristic appearance, generally forming groups of low hills having no particular arrangement and of a reddish tinge due to the presence of iron oxide scattered through the clays. These hills nourish in places one of the richest xerophytic floras I have seen, having a great variety of plants all possessing some type of structure which will enable them to support life in such a physiologically dry situation.

These beds are the most widely spread member of the series, and it seems fairly certain that this wider distribution corresponds to a wider original basin of deposit. In both the Bakhtiyári mountains and on the Bushehr to Ispahan route they occur time after time in the depressions between the lofty ranges of Nummulitic and Cretaceous limestones far beyond the area where the typical clays of the Plateau division extend. A glance at the map will show this. The plateau beds in their typical development are not found further north than the Kamárij plain, while the gypsum beds are found at the base of the series in the Bushehr plain at sea level, and as far east as Bandar Abbás, while there can be no doubt that they are represented by the salt and gypsum series of Lake Urmi and Northern Persia. It will therefore be clear how much wider is their distribution.

As no definite line can be drawn between the gypsum beds and the plateau beds I naturally am not prepared to deny that the lowest beds of the *Ostrea verleti* division occurring immediately above the typical development of the gypsum beds are not contemporaneous with portions of the Fars series further north which I have classified with the basal division. I merely want to give expression to the idea that these lowest beds were deposited on the margins of a large expanse of

sea which was being gradually contracted and converted into dry land. This process was continued beyond the period of gypsum formation as we have a rapid thinning out of the plateau beds from 14,000 to 15,000 feet between Bushehr and Shiraz to 7,000 feet in the Kotal Kamárij. On the other hand in the eastern part of Persia it appears that an extension of the sea area took place subsequently to the deposition of the basal gypsum beds. This conclusion is based on the circumstance that in spite of the development of beds of rock gypsum some 300 feet thick at Khamir, Blanford does not appear to have found any trace of these thick beds of gypsum in traversing the series inland from Gwádar as they invariably appear at the base of the series throughout the whole of the large area where I have had the opportunity of observing them. I am of the opinion that at Khamir and Bandar Abbás we are nearing the margin of the original sea in which these basal gypsum beds were deposited along with limestones and clays and that extensive overlapping occurs.

Evidences of neighbouring land during this basal gypsum period are perhaps to be found in the pebble bed in Henjám and Qishm, which rests directly on the Hormuz series, and passes up into the somewhat newer coast division of the Fars series, and in the conglomerates which Blanford states to occur in the series. The thin-bedded sandstones which are the lowest beds that Blanford saw, are then probably contemporaneous with the sandstones which appear in nearly all sections above the basal gypsiferous marls and clays. If this is so, these sandstones of Blanford's do not represent the oldest beds of the series, but there was a shallowing of the Miocene ocean bed east of Bandar Abbás, and later a gradual depression of the land resulting in the gypsum beds being overlapped by later deposits. It is noteworthy, however, that Mr. Vredenburg in traversing during last year Makrán from Kelát to the coast found a series of strata lithologically similar to and perfectly conformable to Blanford's Makrán coast deposits without any trace of thick beds of gypsum. He considers these to include beds of Lower Miocene or even Oligocene age, that is to say, beds older than the basal beds of the Fars series,

In such cases a portion of this great series of Mr. Vredenburg's must have been contemporaneous with the basal beds of the Fars series, and the same may be true of Blanford's area.

It is difficult to be certain to what extent the upheaval, that took place after the basal gypsum beds were deposited, was accompanied by folding, but I incline to the idea that it was only very slightly so and that the plication of these beds took place at approximately the same time as that of the whole Fars series and of the Nummulitics and that their extraordinary and strongly pronounced folding is due to an inherent peculiarity of the beds themselves rather than to a difference in the earth movements by which they were produced.

In considering the age of these beds it will be convenient to state briefly the extent of our knowledge of the beds underlying and overlying them. Their lowest limits of age are defined for us by a section displayed at Khamir in which they rest upon limestones dipping 40° to 50° S. W., containing *Nummulites garansensis* and *N. sublævigatus*, which are therefore of Lower Nari age. At the base of the Fars are beds of buff-coloured sandstone or sandy limestone dipping 35° S. W. with some intercalated pebble beds, generally containing numerous shell fragments, *foraminifera*, *balani*, and oysters. After 40 feet of these, numerous beds of rock gypsum occur interbedded with some thin buff-coloured clays veined with gypsum. After some 250 feet of these the section ends.

Since, however, we can have no reasonable doubt that these gypsum beds are identical with the gypsiferous series of Armenia, we can bring the age-limit yet nearer; for we know that these beds are underlain more or less unconformably by limestones containing numerous fossils of an age which cannot be older than burdigalian. Further, at Shalil in the Bakhtiyári mountains the gypsum beds rest upon a yellowish rubbly limestone, containing a species of *Clypeaster* allied to *C. depressus* of the Gáj of Sind, *Pecten cf. rotundatus* Lam. which Fontannes[1] identified from the Rhone valley and which is

[1] Fontannes: Les Tert. Terr. Rhône, VI, p. 164.

probably burdigalian and has also been found in the Siuhkuh mountains and in the lower beds at Lake Urmi,[1] and *Operculina complanata*. This bed I have no hesitation in assigning to the Urmi series.

The gypsum beds pass up conformably through some 12,000 feet of the *Ostrea verleti* beds into the clays and limestones of the coast, which contain a rich fauna which cannot be newer than messinian.

Mr. Felix Oswald (40, page) considers that the gypsiferous series of Armenia is sarmatian in age. Since, however, the main portion of the Fars series is absent in Armenia he is unaware what an immense thickness of strata must intervene between these gypsum beds and the coast beds of messinian age. Nothing less than the sarmatian and tortonian periods would be required for the deposition of this great thickness of sediment. It is also noticeable that the fauna of the *Ostrea verleti* beds is of a distinctly tortonian type.

From this reasoning it is therefore clear that a helvetian age is the newest that can be assigned to these basal Fars beds, and they are probably no older because the fossils of the Urmi series can hardly be put further back than burdigalian. Let us now consider the fossil contents of these beds themselves and their correlation with Indian strata.

Unfortunately there are very few fossils found in these basal beds. Thin bands of limestone generally never more than one foot thick crowded with shell fragments, are very common. The shells hardly ever weather out, but on fracture the sections of the shells appear in black streaks throughout the compact rock. In one case in the beds at Chinar Rahdar near Shiraz a rock of this kind exhibited numerous specimens of *Clausinella cf. amidei* Sacco. An oyster appears very common in places, which is identical with a species which is found in beds of Gaj age in India. It has never been described, but through a confusion with D'Archiac's species from the Eocene beds of Sind has been generally known as *O. multicostata*, from which

[1] R. B. Newton (38), 443.

species it is quite distinct. An *Anomia* is also fairly common. The *Ostrea* is confined to these lower beds and does not apparently pass up into the plateau series. Fragments of echinoids and decapod crustacea have been obtained, and recently I have seen some foraminifera and cytherids collected from these beds in the Bakhtiyári country by Mr. G. B. Reynolds.

Now this fauna, scanty as it is, contains as its most characteristic fossil an *ostrea* which is identical with the characteristic fossil of the Gaj series, while the overlying beds contain an echinoid, *Echinolampas jacquemontii*, which is the same as a Gaj species and also several mollusca which are identical with Gaj forms,—namely, *Venus aglauræ*, *Astarte hyderabadensis*, *Ostrea cf. plicatula*.

We have also seen that *Ostrea* sp. *aff. multicostata* is found at Kirrind in the Urmi series as well. We have to decide therefore which of these horizons we must correlate with the typical Gaj stage, and there are two points by which we may be guided in so doing. One is that there is an unconformity above the Gaj beds in the typical area, so that typical Gaj fossils may have persisted much later in areas where deposition proceeded uninterruptedly, and therefore that the *Ostrea verleti* beds of Persia may contain typical Gaj fossils without being strictly contemporaneous with the Gaj strata of Sind, since the fauna is too small to draw precise conclusions. The other is that *Ostrea sp. aff. multicostata* is not found in strata older than the Gaj, and that although possessing a wide geographical distribution it does not appear in the *Ostrea verleti* beds.

I am inclined therefore to correlate the Urmi series with the Gaj of Sind. It so happens that we have more data available for settling the age of the Gaj. Mr. E. Vredenburg[1] has shown that the co-existence of reticulated nummulites and lepidocyclines in the Lower Nari of Sind marks it as stampian. It seems not unnatural therefore that the Upper Nari should be aquitanian and the Gaj burdigalian in age although Mr. Vredenburg puts down the Gaj as upper aquitanian. Again there is a vertebrate fauna of aquitanian age contained in the

[1] *Rec. Geol. Surv. Ind.*, XXXIV, p. 92.

so-called Bugti beds to which the present writer [1] has called attention. These beds represent a local facies of the Upper Nari, probably passing into the Gaj, so that this argument gives us an age for the Gaj at least as old as burdigalian.

The table on page 25 exhibits in concise form the correlation of these various beds in Sind, Baluchistan, Persia, and Armenia.

I can see no proof that these gypsum beds are a continuation of the sarmatian of the Caucasus. On the other hand with such evidence as this before one, we can hardly err in following up the suggestion made by Suess [2] and others and definitely assign these beds to the Schlier period, which was characterized by the same occurrence of very widespread phenomena leading to the formation of salt and gypsum. This will come between Suess' first and second mediterranean stages, and according to the at present most generally accepted classification at the base of the Miocene.

With regard to the origin of these vast beds of gypsum, I would suggest that their formation is due to the effusion of sulphurous fumes in this area, which up to recent times we know to have been one of vulcanicity and that these vapours reacted with the carbonate of lime in the water, resulting in the deposition of sulphate of lime as gypsum. It does not seem probable that the formation of the gypsum was due to the concentration of the sea water, for not only have we no evidence of a drying up of the ocean bed accompanying or succeeding the formation of the gypsum beds, but in an open sea of such a large area as we know the Lower Miocene seas of Fars times to have covered it seems impossible that such concentration could have occurred.

2. *Ostrea verleti beds.*—These beds make up by far the thickest portion of the Fars series although the actual area over which they

[1] *Rec. Geol. Surv. Ind.*, XXXVI, p. 45. Since writing the paper referred to, an examination of these beds in the field has convinced me that they correspond to the Upper Nari series of Sind and are aquitanian in age. Certain fossils, of which *Mastodon angustidens* var. is the most important, were erroneously assigned to the same series as those of an older type, while really occurring at the base of the much newer Siwalik series.

[2] Suess, E. (24), 405.

are exposed may not be equal to that covered by the basal gypsum beds.

They consist of blue or red clays and marls, rapidly alternating with sandstones and thinly bedded rubbly, fossiliferous limestones. The limestones seem to be more frequent in the lower beds while sandstones predominate higher up in the series, and to a large extent even replace the clays. Veins of gypsum are a very constant feature of these beds. As has been already remarked, there is no actual line to be drawn where the gypsum beds end and the plateau division begins, and in every place where I have observed the two in contact there has been a gradual passage from beds in which gypsum and sandy limestone predominate into characteristic clays and marls with thin interbedded limestones and sandstones, in which beds of gypsum when they do occur are not more than about one foot thick.

In the section of them displayed between the Bushehr plain and the Kotal Malo a thickness of fourteen to fifteen thousand feet must be exposed. They appear to thin off going north as between the Konartakhta plain and the Kotal Kamárij this thickness appears to be reduced to some eight thousand feet. As far as Bandar Abbás they invariably overly with perfect conformability the series of gypsum beds.

The general lithological similarity of these beds to those which Blanford has described as met with in his journey inland from Gwádar is very striking.

Further Dr. Blanford himself considered that the beds in Henjám and Qishm belonged to the same series which he named the Makrán group and the comparison of Dr. Blanford's Gwádar fossils with those from Henjám and Qishm entirely confirm this opinion. The latter I know pass down with perfect conformability into the *Ostrea verleti* beds, as is shown by the magnificent section seen on the coast between Khamir and Lingah.

The beds at Gwádar, however, from which Dr. Blanford obtained all his fossils as also a series of fossiliferous nodules which occur at Ormara and which have been partially described by Mr. R. Bullen

Newton (39) belong most certainly to a higher horizon than the *Ostrea verleti* beds.

It is therefore proposed to correlate with the *Ostrea verleti* beds only that portion of Blanford's Makrán series which lies below the coast section. Dr. Blanford obtained no fossils from this portion of the series and has provided us with very little information about it.

In this connection, however, it is important to know that Mr. E. Vredenburg has lately seen beds of the same series much further inland than the coast at Gwádar, and that he considers them as giving palæontological evidence of a much older age.

Fossils are confined in this division almost entirely to the limestone bands, but here they are exceedingly abundant though often only as unidentifiable casts. The following is a list of the fossils which have been examined. They have not as yet been described, but their affinities have been as far as possible ascertained :—

Crustacea.

Balanus sp.

Gasteropoda.

Natica sp.

Cypræa sp.

Lamellibranchiata.

Ostrea verleti Desh.

Ostrea sp. *aff. plicatula* (Gaj form)

Ostrea sp. *aff. subvesiculosa.*

Pecten sp.

Pecten substriatus D'Orb.

Spondylus sp. cf. crassicostatus.

Venus aglauræ Brongn.

Venus sp.

Astarte hyderabadensis D'A. & H.

Lucina sp.

Arca sp.

Arca sp.

Cardium sp.
Lutraria sp. *cf. lutraria* L.
Lithodomus sp. *cf. affinis* Mart.

Echinodermata.

Temnopleurus sp.
Cidaris sp. ind.
Echinolampas jacquemontii D'A. & H.
Echinolampas sp.
Moira sp. *aff. antiqua* Dunc.
Agassizia sp. *aff. lovisatoi* Cott.

Hydrozoa.

Cellepora polythele Reuss.
Ceriopora palmata D'Orb.

Of these *Ostrea verleti* Desh., which is a widespread fossil in the series, also occurs in the Lake Urmi beds (R. B. Newton, 31), while Mr. E. Vredenburg has found it in association with Gaj fossils in the province of Makrán. It occurs in Morea (Deshayes); Siokuh mountains, Persia (Fuchs); Egypt (Fuchs); Azores, etc. (Mayer-Eymer); Crete (Rawlin); Cyprus (Gaudry); Malta (Wright); all these deposits are Miocene and probably Lower Miocene.

Venus aglauræ is also found in the Lake Urmi beds and is a common fossil in the tortonian of the Vienna basin.

Echinolampas jacquemontii is a common fossil in the Gaj beds, *Ostrea* sp. *aff. plicatula* is found at the top of the Gaj, and *Astarte hyderabadensis, Pecten* sp., and *Venus aglauræ* are all as abundant in the Gaj as they are in the Fars series. *Venus aglauræ* is also found in the Nari.

Moira antiqua, to which the Fars fossil is very closely allied, is very abundant in the Gaj series of Kachh.

Agassizia lovisatoi is found in the Miocene of Sardinia.

Pecten substriatus D'Orb., with which the Fars fossil is undoubtedly identical, occurs in the Vienna Miocene from the basal sandstones up to the Leithakalk.

Cellepora polythele and *Ceriopora palmata* are abundant in the Leithakalk of the Vienna basin, and a variety is found in the Siuah oasis which Blackenhorn refers to the helvetian.

This fauna, though not affording very precise data, corresponds in a general way with that of the Gaj series on the one hand and of the tortonian stage of the European Miocene on the other. The series doubtless includes beds that are at a higher as well as at a lower horizon than that mentioned. The question is further discussed on page 32.

3. *Coast division or Pecten vasseli beds.*—It is from this part of the Fars series alone that the fossils come which have hitherto been mentioned or described; consequently to this alone do the remarks of various geologists on the Makrán series apply.

Professor Duncan (25) has described certain echinoids, chiefly from Kharag and Henjám. Mr. R. Bullen Newton (39) has described some of the fossils obtained from the concretionary nodules at Ormara, and finally Dr. Blanford (23) gave a provisional list of some shells collected at Gwádar.

The rocks in general are pale grey clays or marls sometimes passing into a more calcareous rock which may be described as a soft argillaceous limestone. These beds often contain concretionary calcareous nodules, as in Henjám and markedly at Ormara and other places on the Makrán coast.

Interbedded with these are thin calcareous bands crowded with shells, and occasionally grits. The clays are commonly veined with gypsum. They are found along the coast and on many of the islands in the Gulf from Kharag, 35 miles north-west of Bushehr, to Ormara right down on the Makrán coast approaching Karachi.

The dips are often low. Throughout most of Qishm island, in Henjám, and for a considerable distance east of Lingah it is rarely more than 5°, and the same applies to the other Gulf islands. But in places these beds have been suddenly tilted up. Near Khamir they are dipping 20°, at Namakdán in Qishm island they become vertical, and near Jashk the dip is also very steep. It appears also from Mr. E.

Vredenburg's observations on the Makrán coast that the strata here are not, as Blanford thought, almost horizontal, but have a fairly high dip, which is quite imperceptible when these beds are viewed from the sea. Mr. Vredenburg has also remarked that the shelly limestone found at Gwádar and elsewhere is the highest bed in the series. Below these occur sandstones from which in the Hara range and at Chandra Kup he collected fossils which I have had the opportunity of examining. Below these again are clays, the upper portions of which contain concretionary nodules.

Near Khamir a perfectly conformable passage can be traced from these beds down into the bluer marls, with beds of gypsum and marls containing *Ostrea verleti* Desh. and echinoids of an older type.

It is certain that these beds correspond to a period of depression as they often rest directly on the older rocks of the Hormuz series sometimes, as at Henjám and Qishm, with a well-marked conglomerate at their base.

It is manifestly impossible to name any thickness for the coast division, because one cannot draw the line anywhere between them and the *Ostrea verleti* beds. If one considers the beds which in Henjám overlie the conglomerate we have a thickness of 300 feet. In the Namakdán section in Qishm about 600 feet are exposed, while the Makrán coast sections cannot be more than 1,000 feet. One thousand feet therefore may be considered to cover the highly fossiliferous upper beds of the Fars series, which are separated by a distinct interval from the next lower fossiliferous beds in the series, which also exhibit certain marked lithological changes.

On page 41 and following will be found a complete list of the fauna of this portion of the Fars series. In this are included both the species which have been already described by Professor P. M. Duncan and Mr. R. B. Newton, as well as the numerous forms which I have myself examined, although their descriptions are as yet unpublished. I have referred to them, where new to science, by the species to which they present a near affinity. Of the localities mentioned those in the last four columns belong to the newest beds of

the series. The nodular formation and the sandstones are evidently not much older, while regarding the first three localities I can state nothing so definite. It is highly probable, however, that they are essentially of the same age as the others.

It remains now to consider the bearing of this fauna on the question of the age of these beds. The first point which must strike one is its absolutely endemic nature. This might well have been expected from Duncan's and R. B. Newton's results. These authors in no case found an absolute identity with a hitherto described species whether recent or fossil. It is also in complete accordance with the character of the recent molluscan fauna of the Persian Gulf, which Mr. Cosmo Melvill[1] has so admirably catalogued for us. This marine *cul-de-sac* evidently is entitled to rank as a distinct zoological district.

In some respects this is unfortunate for us geologically, for we have no choice save to consider the fauna largely on its own merits, not being able to establish a sufficient number of specific identities to correlate it with any known horizon.

Out of 120 species only 12, or 10 per cent., are identical with recent forms, and of these some three or four possess varietal differences. Now in the marine stage of the pontian in Italy known as the messinian there are 17 per cent. of living species, so that even allowing for individual differences of opinion in the interpretation of species, it is impossible to assign an age to these beds younger than the pontian.

While many of the species are closely related to living forms, there are many whose affinity to the species named is very remote. Examples of these are to be seen in *Eglisia* n. sp. *aff. leptomita*, *Purpura* n. sp. *aff. succincta*, *Leiodomus* n. sp. *aff. taheitensis*, *Solecurtus* n. sp. *aff. exaratus*, *Chione* n. sp. *aff. mekranica*, while a certain number are so distinct that it is impossible to compare them with recent forms. Such are *Pecten vasseli*, *Pecten* sp. *aff.*

[1] I have to express my indebtedness to Mr. Cosmo Melvill for allowing me to examine his fine collection of Persian Gulf shells and for giving me much valuable help in the discrimination of some of the species.

Westendorpianus, *Chlamys* n. sp., *Spondylus* n. sp., *Cytherea* n. sp., *Clementia* n. sp., *Dosinia* n. sp., *Lutraria* n. sp., *Cuspidaria* n. sp. *aff. brucei.*

A few are of an ancient type, *viz. Arca clathrata*, *Pinna* sp. *cf. pectinata*, *Chlamys* (*Aequipecten*) *Bicknelli*, *Venus astarteoides*, *Corbula cocconii*, *Turritella archimedis*, *Tornatina* sp. cf. *lajonkarieana*, *Ringicula paulucciæ*, and date back to the helvetian, although they are often recorded from messinian or even plaisancian beds in Italy.

Dolium hochstetteri, *Melongena pugilina*, *Mactrinula* sp., *Lithodomus affinis*, *Clementia papyracea* (a recent form allied to *C. cumingii*), *Sciobicularia angulata*, and *Temnopleurus toreumaticus* have been found in the Miocene beds of Burma, Java, or Sumatra.

Comparing the fauna now with the Indian beds of an older date, such as the Gaj of Sind and Baluchistan, the only identity is in *Venus astarteoides.*

One cannot therefore consider that these beds approximate very nearly to the Gaj in age, even allowing for local differences. If the Gaj is burdigalian, it seems impossible to make these beds older than sarmatian.

The *Pecten vasseli* beds as a whole may therefore be considered as sarmatian or pontian, and considering that the affinities of the fossils from the newest beds are nearer to recent than they are to Gaj species, I incline to a pontian age, for these topmost beds at all events.

	Baranbab and Gwâdar clays.	Ras Malân clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones	Gwadar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
ECHINOIDEA.									
Cidaris n. sp.	...	...	...	...	...	×	...	×	...
Goniocidaris n. sp. *aff. affinis* Dunc.	...	...	...	...	...	×	...	×	...
Temnopleurus simplex Dunc.	...	...	...	...	...	×	...	×	...
Temnopleurus toreumaticus Ag. var.	...	...	...	...	...	...	×	×	...
Temnopleurus n. sp. α *aff. hardwickii* A. Ag.	...	...	...	...	...	...	...	×	...
Temnopleurus n. sp. β *aff. hardwickii* A. Ag.	..	...	...	...	...	...	...	×	...
Salmacis sp.	...	...	...	...	...	×	...	...	...
Clypeaster suffarcinatus Dunc.	...	...	...	...	...	...	...	...	×
Clypeaster n. sp. *aff. scutiformis* Lam.	...	...	...	...	...	...	...	×	...
Laganum tumidum Dunc.	...	...	...	...	...	...	...	...	×
Echinodiscus auritus Leske var.	...	...	...	...	...	...	...	...	×

FAUNA OF THE *Pecten Vasseli* BEDS OF THE FARS SERIES.

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
ECHINOIDEA—*contd.*									
Schizaster n. sp. *aff. Baylei* Cott	...	...	...	...	...	...	...	×	...
Brissus n. sp. *aff. oblongus* Wright	...	...	...	...	...	...	...	×	...
Metalia sp.	...	...	...	...	...	...	...	×	...
Lovenia n. sp. *aff. elongata* Alcock	...	...	...	...	...	...	...	×	...
LAMELLIBRANCHIATA.									
Ledina sp. *cf. fragilis* Chemn.	...	...	...	...	...	×	...	...	...
Anomia sp.	...	...	...	...	...	...	...	...	...
Placuna sp. *cf. placenta* L.	...	...	...	...	...	...	×	...	...
Arca n. sp. *aff. umbonata* Lam.	...	...	...	...	...	×	...	...	...
Arca sp.	...	...	...	...	...	×	...	...	...
Arca (*Anadara*) n. sp. *aff. diluvii* Lam.	...	...	...	...	...	×	...	...	...
Arca (*Acar*) *clathrata* Defr.	...	...	...	...	...	×	...	...	...

FAUNA OF THE *Pecten Vasseli* BEDS OF THE FARS SERIES.

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I	Kharag I.
LAMELLIBRANCHIATA—*contd.*									
Arca blanfordi Newt.	...	...	...	×	...	...	...	...	...
Parallelopipedum tortuosum L. var.	...	...	...	...	...	×	...	...	...
Pectunculus (*Axinæa*) n. sp. *aff. amboynensis.*	...	...	...	...	...	×	...	...	...
Lithodomus sp. *cf. affinis* Mart.	...	...	...	...	...	×	×	×	...
Pinna sp. *cf. pectinata* L.	...	...	...	×	...	...	...	...	...
Ostrea n. sp. *aff. verleti* Desh.	...	...	...	...	...	×	×	...	×
Ostrea caudatus var.	...	...	...	...	...	×	...	...	...
Ostrea n. sp. *aff. iridescens* Gray	...	...	...	...	...	×	...	...	...
Pecten vasseli Fuchs	×	...	×	...	...	×	×	×	...
Pecten n. sp. *aff. Westendorpianus* Nyst	...	×	×	...	...	...	...	...	...
Pecten n. sp. *aff. dorotheæ* Melvill	...	...	...	...	...	...	...	...	×
Chlamys lividus Lam.	...	...	...	...	...	...	...	...	×

FAUNA OF THE *Pecten Vasseli* BEDS OF THE FARS SERIES.

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
LAMELLIBRANCHIATA—*contd.*									
Chlamys reissi Bronn.	...	...	...	...	...	×	...	×	...
Chlamys n. sp.	...	...	...	...	×	...	...	...	..
Chlamys n. sp. *aff. singaporinus* Sowb.	...	×	...	...	..	×	..	....	...
Chlamys n. sp. *aff. celestini* Font.	...	×	...	...	...	×	...	...	...
Chlamys (*Aequipecten*) *bicknelli* Sacco	...	...	...	...	×	...	×	×	×
Pecten n. sp. *aff. solarium* Lam.	...	...	...	...	...	...	...	...	×
Pecten (*Plagioctenium*) n. sp. *aff. ventricosus* Sowb.	...	...	...	...	...	...	×	...	...
Manupecten sp. *aff. pes felis* L.	...	...	...	...	...	×	...	...	...
Spondylus n. sp. *aff. exilis* Sowb.	...	...	...	...	...	...	...	...	×
Spondylus n. sp.	...	...	...	...	...	...	...	...	×
Lucina (*Codakia*) n. sp. *aff. fibula* Rve.	...	...	...	...	...	×	...	...	...
Lucina (*Cyclas*) n. sp. *aff. semperiana* Issel.	...	...	...	...	...	×	...	...	...

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
LAMELLIBRANCHIATA—*contd.*									
Tellina (*Moera*) n. sp. *aff. pygmæa* Phil.	...	...	...	...	...	×	...	...	...
Scrobicularia (*Loxocapsa*) n. sp. *aff. angulata* Chemn.	...	...	...	...	...	×	...	...	...
Mactra makranensis Newt.	...	...	...	×	...	...	...	...	...
Mactra sp.	...	...	...	...	...	×	...	...	...
Trigonella n. sp. *aff. tumida* Chemn.	...	...	...	...	...	×	...	...	...
Mactrinula plicataria L.	...	...	...	×	...	...	...	..	...
Mactrinula tryphera Melvill	×	...	...	×	...	...	...	...	...
Cytherea n. sp. α	...	...	×	...	...	...	...	...	...
Cytherea n. sp. β	×	...	...	...	...	...	...	...	...
Callista n. sp. *aff. florida* Lam.	...	...	×	...	...	...	...	...	...
Callista n. sp. *aff. phasianella* Desh.	...	...	×	...	...	...	...	...	...
Circe n. sp. *aff. corrugata* Chemn.	...	...	×	...	...	×	...	...	...

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
LAMELLIBRANCHIATA—*contd.*									
Tapes textrix Chemn.	...	...	...	×	...	...	...	...	...
Tapes n. sp. *aff. hiantina* Lam.	...	...	...	...	...	...	...	...	...
Tapes n. sp. *aff. papilionacea.*	...	...	...	×	...	...	...	...	...
Tapes sp. *aff. marmorata* Lam.	...	...	...	...	...	...	...	...	...
Dosinia sp.	...	...	...	×	...	...	...	...	...
Dosinia n. sp.	...	...	...	...	...	×	...	...	...
Chione n. sp. *aff. mekranica* Melv.	...	...	...	...	...	×	...	...	...
Venus astarteoides D'A. & H.	...	...	×	...	...	...	...	...	...
Clementia n. sp. *aff. cumingii* Desh.	×	...	...	×	...	×	...	...	...
Clementia n. sp. *aff. non-scripta* D'A. & H.	×	...	×	...	...	...	...	...	...
Clementia n. sp.	×	...	...	...	...	...	...	...	...

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwadar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
LAMELLIBRANCHIATA—*concld.*									
Cardium melvilli Newt.	...	...	...	×	...	...	...	...	...
Cardium sp. *aff. omanense* Melv.	...	...	...	...	...	×	...	..	...
Chama n. sp. *aff. spinosa* Broderip	...	...	...	...	...	×	...	...	...
Chama sp. *aff. gryphina* L.	...	...	...	...	...	×	...	...	...
Chama sp.	...	...	...	...	...	×	...	...	...
Lutraria n. sp.	...	...	...	...	...	×	...	...	...
Corbula cocconii Font.	...	...	...	...	...	×	...	...	...
Solecurtus n. sp. *aff. exaratus* Phil.	...	...	...	×	...	...	...	...	...
Solen sp.	...	...	...	×	...	...	...	...	...
Cuspidaria n. sp. *aff. Brucei* Melvill	...	...	...	...	...	×	...	...	...

FAUNA OF THE *Pecten Vasseli* BEDS OF THE FARS SERIES.

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
SCAPHOPODA.									
Dentalium octogonum Lam.	...	...	...	...	...	×	...	...	...
Dentalium sp.	...	...	...	...	...	×	...	...	...
GASTEROPODA.									
Minolia sp.	...	...	...	..	...	×	...	...	...
Scala (*Acrilla*) n. sp. *aff. acuminata* Sowb.	...	...	...	...	...	×	...	...	...
Eglisia n. sp. *aff. leptomita* Melv. et Sykes.	×	...	...	...	...	...	...	...	...
Natica sp. *aff. ampla* Phil.	...	...	...	.	...	...	...	..	...
Natica sp.	...	...	...	...	...	...	...	...	...
Tugurium makranense Newt.	...	...	...	×	...	...	...	...	...
Solarium n. sp. *aff. modestum* Phil.	...	...	...	...	...	×	...	...	...
Cerithium (*Vertagus*) n. sp. *aff. kochi* Phil.	...	...	...	...	...	×	...	...	...
Turritella archimedis Hoernes	...	...	...	...	...	×	...	...	...
Turritella n. sp. *aff. turris* Bast	×	...	..	×	...	...	...	...	...

	Barambab and Gwadar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwadar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
GASTEROPODA—*contd.*									
Turritella tricarinata Brocc.	..	...		×	...	...	...	...	...
Cypræa sp.	...	...	...		...		...	...	...
Dolium costatum Menke	...	...	...	...		...	...	...	...
Dolium townsendi Newt.	..	...	...	×	...	..	...	...	...
Dalium hochstetteri Mart.	...	...	...	×	...	...	...	...	...
Lampusia sp. *cf. affinis* Desh.	..	...	.	×	...	..	...	...	...
Gyrineum n. sp. *aff. albivaricosum* Rve.		...	...	...	.	×	...	...	...
Murex n. sp. *aff. ternispina* Lam.	...	..	...	×	...	...	...	...	...
Murex n. sp. *aff. rectispina* Brocc.	...	...	...	×	...	...	...	...	...
Murex n sp. *aff. brevispina* Lam.	...	...	×	...	...	...	,	...	...
Purpura n. sp *aff. succincta* Martyn	..	..	...	×	...	...	...	...	...

	Bararbab and Gwádar clays.	Fas Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
GASTEROPODA—*contd.*									
Leiodomus n. sp. *aff. taheitensis* Gmel.	...	...	...	×	...	...	...	...	...
Neptunea burrowsi Newt.	...	...	...	×	..	...	...	...	...
Melongena pugilina Born.	...	...	×	...	...	...	...	...	...
Latirus n. sp. *aff. lynchoides* Bell.	...	...	×	...	...	...	..	...	...
	...	...	...	×	...	...	...	...	...
Ancilla n. sp. *aff. sismondana* D'Orb.	...	...	...	×	...	...	...	...	...
Terebra sp. *a*	...	...	...	...	...	×	...	...	...
Terebra sp. *β*	...	...	...	...	...	...	...	...	...
Conus (*Dendroconus*) sp. *aff. ponderosus* Beck.	...	...	...	×	...	...	...	...	...
Conus (*Leptoconus*) n. sp. *aff. orbignyana* Audouin.	...	...	...	...	...	×	...	...	...
Conus (*Leptoconus*) n. sp. *aff. milesi* E. Smith.	...	...	...	...	...	...	...	...	...
Conus n. sp. *aff. gubernator* Hwass	..	...	...	×	...	...	...	...	...

	Baranbab and Gwádar clays.	Ras Malán clays.	Clays near Jashk.	Ormara nodular formation.	Chandra Kup and Hara range sandstones.	Gwádar shelly bed.	Qishm I. (eastern end).	Henjám I.	Kharag I.
GASTEROPODA—*concld.*									
Pleurotoma (*Surcula*) n. sp. *aff. catena* Rve.	...	...	...	...	...	×	...	...	...
Tornatina sp. *cf lajonkaireana* Bast.	...	...	...	..	...	×	...	...	...
Ringicula pauluccia Morlet	..	...	...	...	...	×	...	...	...
CRUSTACEA.									
Balanus tintinnabulum L.	...	...	...	×	...	...	...	...	...
Neptunus arabicus H. Woodw.	...	...	...	...	...	.	...	...	...
BRYOZOA.									
Membranipora lacroixi V. Audouin	...	...	...	×	...	...	...	...	...

10. Bakhtiyári Series.

These beds, to which I propose to give the name of the Bakhtiyári series, correspond to the upper portion of Loftus' gypsiferous series.

There is beyond any doubt always a great unconformity between them and the underlying part of Loftus' gypsiferous series, here described under the name of the Fars series, the one being a series of river deposits laid down directly on the marine beds of the other after their elevation into dry land. The unconformity is by no means always distinctly visible, owing to the fact that but little disturbance of the strata seems to have taken place between the Fars and the Bakhtiyári periods, the Fars sea bottom having been merely elevated without being folded. Sometimes where the Fars sediments are sandstones it is not even easy to say where the line is to be drawn between the two series These beds have shared in all the folding of the Fars ; only the more resistant nature of these gravels has preserved them from the extreme overfolding, to which the softer gypsiferous marls and shales of the Fars series have been subjected. The conglomerates are to be seen in many places directly resting on both Nummulitic and Cretaceous limestones, having a generally high dip which is perfectly conformable to that of the Nummulitics, though not so to the Cretaceous. They are very largely developed in the Bakhtiyári mountains, as well as in the plains of Khuzistán and Luristán, having been traced by Loftus as far to the north-west as Mosul on the Upper Tigris. They probably extend some distance to the south and south-east of the caravan road between Shiraz and the coast, but seem not to be represented in the beds of Pliocene age found in the neighbourhood of Qishm island and Lingah.

The locality where I have found it possible to trace their character to the best advantage is the district lying between the bridge at Dáliki and the plain of Kazrun, on the caravan road from the coast to Shiraz.

Throughout this district they are seen to lie quite irregularly on different beds in the Fars series and attain a thickness of rather more than 1,000 feet.

They consist of detrital deposits of every degree of coarseness from a conglomerate containing pebbles half as large as a man's head down to a fine sandstone. The most characteristic rock of the formation is a conglomerate composed of red and green chert pebbles. In this deposit are also limestone pebbles, some of which contain nummulites, while others which are partially crystalline are probably Cretaceous. Pebbles of some more ancient, probably Cretaceous, conglomerate are occasionally seen. This although never forming a band more than some 10 feet thick is most widely spread and would seem to mark a constant horizon corresponding to a period of flood when the river sediments spread far beyond their usual limits. Here and there one meets with gypsum, but it is not abundant and is more likely to have been derived from the Fars series than to have originated contemporaneously. There seems no ground for supposing that this series varies much in character throughout the whole of the area where it is found. Instances such as that quoted by Loftus (8, 268) where Mr. Hamilton is mentioned as having noticed sandstones underlying the gypsiferous marls, are probably not to be explained, as Loftus suggests, by varying condition of deposition in various areas, but by the occurrence of thrust faulting, which accompanies the extreme folding which the gypsiferous marls have undergone, and which has in several cases completely reversed the natural order of stratification. The denudation of the fold or of the upper beds in these cases of folding or thrust faulting has often obliterated every outward trace of what has taken place.

The series is practically unfossiliferous. The only occurrence of such known was the footprint of some carnivorous animal, which W. K. Loftus found in a red sandstone at Housseineah. This absence of fossils makes it impossible to come to any definite opinion as to its age. It is certainly later than the *Ostrea verleti* beds, that is, post-sarmatian, and as it has shared in the folding of the last orogenic period, it cannot be newer than Pliocene. These beds therefore correspond in age as they undoubtedly do in general character

to the great Indian Siwalik series. They are to all intents and purposes Siwalik, but to what part of that immense series we are to assign them must remain unknown until fossils are discovered in them. It may well be that they are contemporaneous with the uppermost beds of the Fars series developed on the coast which are messinian in age, or they may be later even than these.

11. Freshwater Beds of Sur.

These were seen by A. v. Krafft and R. D. Oldham some 30 miles from Sur on the coast of 'Omán south-east of Muscat. They consist of shaly and sandy limestones and sandstones and form a broad synclinal fold striking north-west and south-east and extending a distance of some 10 miles. Their age is unknown, but they overlie the newest tertiaries in this part of 'Omán, and must evidently belong to a period subsequent to the uplift of the tertiaries. A. v. Krafft is therefore doubtless correct in stating that they are at least Miocene and probably of Pliocene age.

12. Foraminiferal Oolite or "Miliolite."

Of widespread occurrence in and near the Persian Gulf and on the south-eastern coast of Arabia is a limestone of an exceedingly light and crumbly nature made up of rounded calcareous particles resembling oolitic grains, with some intermingled sand grains, the whole being bound together by a calcareous cement. The granules consist for the most part of internal casts of foraminifera or other small calcareous organisms, surrounded by a coating of lime, which can often be dissolved away by acid exposing the structure of the organic nucleus. True oolitic grains also occur. The sand grains form a very inconsiderable portion (less than 2 per cent.) of the whole.

It is the same as Carter's "miliolite," and in most cases is identical with a widely spread formation on the Káthiawár coast.

It has been found on many of the Gulf islands at an elevation of as much as 450 feet above the sea. In Qishm and Henjám islands, where I saw it myself (pages 127 and 135), it is almost horizontally

bedded and evidently unconformable to the upper beds of the Fars series. I have here seen it interbedded with fine-grained sandstones, and similar beds have been noticed in Káthiawár. In Qishm island it is overlain by a conglomerate containing sub-recent shells, such conglomerates occurring at various elevations down to sea level. Near Muscat it is found frequently, resting on the Nummulitics. Here recent wadis have been cut through it, and in some cases a conglomerate deposited on top.

Generally the grains in the "miliolite" are small and hardly visible to the naked eye, but in Daiyinah island there is a deposit containing oolitic grains of large size very loosely cemented together with fragments of shells, echinoid spines, etc.

Carter has described beds of "miliolite" at Marbat and Dofar on the south-eastern coast of Arabia containing marine fossils much larger in size than the grains of the deposit.

In Káthiawár Fedden found a few land shells in this formation.

In the island of Bahrain the same deposit occurs in two somewhat similar situations, in the one case in the old bed of a river, in the other on the sides of a steep ravine. Both are false bedded. In the latter position it dips down into a cave at an angle of 20°.

False bedding is a common characteristic of the Káthiawár "miliolite."

Dr. J. W. Evans (32) and Mr. F. Chapman (33) have discussed the question of the formation of these limestones. They have adopted the view that they are wind deposits. Much of the material of which they consist is admittedly of sedimentary origin in the first instance; such material was thrown up as part of a littoral deposit which was subsequently redistributed, its lighter portions being transported by wind agency to their present position, which in past times may not have been so far removed from the sea as it is at present. Many of the occurrences, notably those in Bahrain, are strongly in support of this theory, and it is probable that most of the deposits of "miliolite" are of æolian origin. At the same time we can hardly doubt that in certain localities where the "miliolite" contains larger

organisms or is made up of much true oolite, the strata were laid down in shallow water and we find them now *in situ* at the place of their original formation. Mr. F. Chapman has concluded that the foraminifera in the miliolitic deposit afford no evidence of an earlier age than late Pliocene, and it seems most likely from the relations of the rock to the Fars series and to sub-recent littoral conglomerates that it is to be regarded as Pleistocene. It is interesting to note that the climatic and atmospheric conditions which have accumulated these thick æolian deposits in Pleistocene times have continued right up to the present time, and in Qishm we see side by side the deposits of the past and those of to-day.

13. Recent or Sub-Recent.

Developed along the Persian coast of the Gulf and in many of the Gulf islands is a shallow water or *littoral concrete*, often almost entirely made up of shells in a beautiful state of preservation, and belonging entirely to recent species. It is the same formation which is found in Bombay harbour and on the Káthiawár coast. It forms cliffs some 20 feet high at Jashk and Halul island and is found capping the Fars beds in Qishm, Tunb, and other islands at a height of 500 feet above sea level. It forms the substratum upon which the town of Bushehr is built and the houses are largely constructed of it. It extends more than 5 miles inland behind Bushehr. The strata are not always perfectly horizontal, and occasionally they are with difficulty distinguishable from some of the less disturbed beds of the underlying Fars series, where the one formation shades gradually into the other and resembles it lithologically. These raised beach deposits are of course evidence of rise of land in recent times, and this, as we shall see, is the latest movement to which the Gulf has been or is now being subjected.

Around the island of Bahrain, and probably in other places as well, are sub-recent limestones of coral formation forming islands which rise to 60 feet above the sea. These have been much denuded by the sea, and the shores of Jiddi and Raka are strewn with huge blocks which have tumbled from the cliffs above.

Wind deposits are frequent in several places; these take the form either of vast tracts of shifting sand, such as I noticed in the eastern half of Qishm island, where much of the underlying rock is covered by sand which is probably not more than 10 to 20 feet deep. Similar areas of blown sand exist in the desert regions of Arabia. On the Pirate coast is a long line of stable red sandhills some 100 feet or more in height, and forming a belt extending inland for 8 miles or more. They owe their colour to numerous round grains of chert. The sands are somewhat compacted, and the whole is bound together by a xerophytic vegetation.

The Mesopotamian alluvium includes 1.—Fluviatile deposits which are in course of formation to-day in the neighbourhood of the various rivers. They consist of a tenacious, blue clay, or a grey arenaceous clay with fine sand and gravel.

2.—Marine deposits, which are deltaic in origin and are composed of dark grey or reddish yellow sands and sandy marls. They contain numerous marine shells identical with living species. These estuarine beds gradually pass up into the more recent fluviatile alluvium. Rawlinson, by careful measurements extended over a period of 30 years, found that in that time the deltaic deposit had advanced one mile towards the Gulf. Barns has calculated the amount of material annually contributed to the Gulf by the Shatt El Arab as 25,600 millions of cubic feet based on the assumption that during one-third of the year it carries in suspension one-third its volume of solid matter.[1]

Alluvial deposits are found in Persia high up along the sides of most of the river valleys. They contain no fossils, and though their age cannot be fixed with certainty it is convenient to class them here. In many places they overlie the Fars beds as well as the Bakhtiyári gravels. In Arabia old conglomerates are found along the floors of many of the "wadis." Near Dibah in the Masandam peninsula the wadi is cut out of an old alluvial deposit, which forms cliffs some 50 feet high on either side. Near Muscat the recent conglomerate is

[1] *Cf.* Morgan, J. de: *Mission Scientifique en Perse*, Vol., 284.

deposited unconformably on the ancient Eocene conglomerate which is slightly tilted.

In the interior of Persia most of the great desert plains have been shown by Blanford (20) and others to have been once the sites of salt lakes, which have left well-marked terraces of gravel and clay. It is impossible to state with any certainty the exact age of the various deposits which are considered here. It is not impossible that some of the terrestrial deposits may reach back into the Pleistocene, while those of marine origin may have been deposited at any time subsequent to the depression of the 'Omán coast, which probably occurred in Pleistocene times.

Geological History of the Gulf.

From the facts which have been recorded it is possible to frame some more or less definite conclusions as to the changes which have occurred in the area in past times.

In the present state of our knowledge it is impossible to say much about the history of the most prominent rock system of 'Omán. It seems not unlikely that the 'Omán series takes us into the Jurassic, and it certainly embraces rocks ranging in age from Carboniferous to Trias.

At the close of Jurassic times or early in the Cretaceous there was a great outpouring of basic igneous rock, in the form of huge sills and flows. At the beginning of the Cretaceous great folding and crushing movements took place which folded in these sills and flows among the older limestones, and produced the mountain ranges of 'Omán. In the ocean bed whose southern limit was defined by these upheaved older rocks were deposited the upper Cretaceous beds of Hippuritic limestone, which cover such large areas in Persia, and overlie the igneous rocks of 'Omán. Following closely upon these, and perhaps extending into the Eocene period, occurred a great series of volcanic flows accompanied by the formation of thick beds of salt and gypsum. This volcanic area extended approximately over the space now occupied by the eastern and larger basin of the Persian Gulf proper. It seems likely that shallow water conditions prevailed here, and

some of the lavas and tuffs of the Hormuz series were probably subaqueous. At the same time or a little later, some of the Hippuritic limestone must have been undergoing denudation.

Succeeding this period of volcanic activity, that is to say, in Middle Eocene times, occurred a depression of most of Southern Persia within which the Eocene rocks were deposited. This was accompanied by an upheaval of the volcanic area of the Hormuz rocks into dry land, which formed a barrier separating the Eocene rocks of Persia from those of Bahrain. It seems not unlikely that this land barrier continued through the Upper Eocene and Oligocene. This appears to have been a tranquil period, the distribution of land and sea remaining almost unaltered until Urmi and Fars times.

It is difficult to say what amount of unconformity there is between the latest of these so-called Nummulitic limestones and the lowest beds of the Fars series, but in any case such movements as took place seem not to have tilted the Nummulitics appreciably. It is also certain that the rocks of Fars age must have been laid down over much wider areas than they occupy at present, as outlying patches are found even in Northern Persia, and very little of the Nummulitic area may have been dry land in Miocene times. The southern limits of the Fars sea, on the other hand, seem never to have stretched much beyond the present Persian coast. Minor movements undoubtedly disturbed the sea floor and perhaps elevated the Makrán coast and Eastern Persia before the deposition of the Bakhtiyári grits in Pliocene times. But it was subsequent to this that the tremendous earth movements occurred which folded and faulted Cretaceous and Tertiary rocks alike, and elevated the Mio-Pliocene sea bottom to 9,000 feet above the present sea level. At this epoch then did the present mountain system of Persia originate. The Persian Gulf area itself seems to have been less disturbed, witness the almost horizontal strata of the *Pecten vasseli* beds in Henjám and the gently rolling Eocene rocks of 'Omán and Bahrain. It is on the whole likely that denudation continued over this area, and that the carving out of the topographical features, to which the floor of the Persian Gulf and the Gulf

of 'Omán owe their present contour, was concluded during this period. The limit of this land was doubtless determined by the steep submarine cliff, already mentioned, which runs along the Makrán coast and then cutting across the Gulf of 'Omán runs parallel to the Arabian coast. This feature may have been the result of a fault, but I incline to the idea that it was produced by the denudation of a gradually rising area during Pliocene and possibly Pleistocene times. Then a widespread submergence took place, which buried fathoms deep the steep mountain valleys, river systems and sea cliffs, which had been carved out during so many ages previously. To movements of this nature do we owe the deeply-cut inlets of Masandam, and the islands dotting the Gulf, which are merely isolated peaks of the Hormuz volcanic series just rising above the surface of the water.

In still more recent times an elevatory movement must have been proceeding throughout the Persian Gulf. The flat ledges cut by the sea around Muscat and now raised above sea level, the recent littoral deposits of 'Omán and Persia as well as of the various islands, the sea terraces of Bahrain, are all evidence of a widespread elevation of this area.

In the upper portion of the Gulf the deposits of the great rivers have contributed to this work of reclamation in an entirely different manner. The records of the past furnish us with abundant proofs of how continuous and rapid has been the process by which the cities of antiquity have one by one retired inland from the littoral, and have been replaced by others in sites where once there existed flooded marshes or navigable water.

Part II.—Detailed Descriptions.

CHAPTER I.

THE COUNTRY BETWEEN BUSHEHR AND PERSEPOLIS.

Bushehr itself and the neighbouring country up to some distance beyond the telegraph station of Rishehr and the British Residency at Sabzabad forms a sort of island some 12 miles in length by 4 in width, which is separated from the mainland by a salt marsh, which at certain times of the year is absolutely impassable, and which is always liable to engulph one to the knees in mud if one leaves the caravan track. Bushehr island, if one may call it such, consists of a recent or sub-recent calcareous conglomerate of a similar character to that which is seen at many other places in the Gulf, in Bombay harbour, and on the Káthiawár coast, and made up of shells belonging to recent species. This forms cliffs some 20 feet high and affords an excellent demonstration of the elevation which has taken place in the Persian Gulf in recent times. Bushehr island is in fact an elevated coral reef, which, possibly within historical times, was completely severed from the mainland by sea in the area now occupied by a salt marsh. Most of the houses in Bushehr are built of this shelly concrete, which makes an admirable material for the purpose.

The general character of the country between the Bushehr plain and the Persian plateau may be expressed by saying that to reach Dasht-i-Arjan, which is the highest point of the road between Bushehr and Shiraz, one takes five steps, each of which is represented by a steep mountain pass or *kotal*, which in most countries would be regarded in the present condition of the paths as impracticable, but which in Persia are traversed day after day by thousands of heavily laden mules.

These *kotals* are the Kotal Malo, Kotal Kamárij, the Tang-i-Turku, the Kotal Dukhtar, the Kotal Pir-i-Zan. Each of them

is separated from the next by a flat alluvial plain, sometimes of considerable extent and invariably occupying a synclinal fold.

A dead flat plain some 35 to 40 miles in width stretches between Bushehr and the hills. Near the village of Borasjun are several low hills which run some distance both in a north-west and in a south-east direction. These are composed of an alluvial conglomerate, which is Pleistocene or Sub-Recent and represents the great accumulations of detrital matter which were formerly brought down from the hills of Persia at a time when the rainfall was considerably greater than it is now. At the present day these alluvial deposits are all being eroded. The pebbles contained in it are for the most part limestones. Behind these low alluvial hills rise the Gisakán ranges nearly 6,000 feet above sea level. As is the case with most of the ranges of Southern Persia, it is an anticlinal one and doubtless affords the same complete section of the Fars series, which I saw by travelling over less elevated ground between Dáliki and the Kotal Malo.

At Dáliki alluvial hills are absent and the main range, composed of rocks of the Fars series, rises sheer from the plain. The total thickness of rocks belonging to the Fars series seen here is about 15,000 feet. The basal gypsum beds, which are readily distinguished at a distance by their brilliant red colours or by the white appearance of the gypsum, are as a rule the only beds in which the bending over of the strata to the south-east is shown; the south-easterly dipping portion of the overlying beds has invariably been denuded, and the scarped face is left with the low gypsiferous hills hanging on at the base. Arising out of them at Dáliki is a hot spring at a temperature of 70° C. laden with sulphuretted hydrogen and depositing small amounts of sulphur and bitumen.

The so-called coal of Gisakán farther to the west is nothing but bituminous sandstone. The basal gypsum beds are not everywhere exposed at the foot of this range, but only in the bays to the north-west of Dáliki. The gypsum beds are concealed beneath the overlying marls which here are dipping down into the plain. The strike of the beds varies considerably, and some beds dip into the plain in a north-

westerly direction while others dip south-westerly. The general trend of this range, as in most of the Persian ranges, is north-west to south-east, and there is no doubt that the whole of it belongs to the Fars series. Where it meets the coast at Naband the characteristic basal gypsum beds are again exposed. Whether the other ranges between the Gisakán range and the sea consist of Fars rocks I cannot say.

The following is an account of the beds forming this series as one goes upward from the basal gypsum beds (Sketch Section Pl. I). Two or three prominent bands of limestone containing shell fragments, each over 50 feet thick and separated by marls. One band of limestone is fairly compact and contains veins of calcite, but the others, like most of the limestone in the Fars series above the gypsum bed, are nodular and marly, and a blow of the hammer is sufficient to shatter them to pieces. Alternations of great thickness of gray clays and thinner bands of nodular shelly limestones continue for 5,000 feet. A band of gypsum a foot or more thick was seen in this part of the series. On leaving the plain the dip of these beds is only 15°, but this increases to 30° which is the general dip. The limestones contain *Ostrea verleti*, *Echinolampas jacquemontii* D'A. & H., two or more species of *Pecten* and species of *Natica* and *Cypræa*. The shells are often numerous, but unfortunately they are generally only internal casts and lack individuality. For the next 3,000 feet the same succession of clays with shelly calcareous bands is the rule, but coarse sandstones now occur. Up to Dáliki river throughout the next 4,000 feet these sandstone bands are the predominating features. They are gray in colour and fairly hard. Interbedded with them are blue clays, with veins of gypsum running across the bedding. The Dáliki river at this point runs in a strike valley between sandstone cliffs. Overlying these sandstone beds is a very fossiliferous argillaceous limestone crowded with *Temnopleurus* sp., *Venus aglauræ* Brongn., *Astarte hyderabadensis* D'A. & H., *Lithodomus* sp. *cf. affinis* Mart.

The remaining 2,000 feet of the section show thick succession

of red clays with thin bands of red sandstone and finally blue clays. All of them are thickly pierced by 1 or 2-inch veins of gypsum running in all directions. This brings us to the foot of the Kotal Malo. The steep pass which has now to be negotiated consists entirely of rocks of the Bakhtiyári series. This series is exposed in this region to a much larger extent than I have seen it elsewhere during this journey. It attains a thickness of rather more than 1,000 feet. The map in plate XV will show the distribution of it over the area. The whole is displayed on the sides of the Kotal Malo, where they exist as a shallow syncline of which one scarp side is presented to the pass, and the other forms the steep conspicuous bluff which overlooks the Konartakhta plain. The lowest beds are fine sandstones with thin layers of sandy clay of a deep red colour, which makes the beds of this series conspicuous from a very great distance.

Small quantities of gypsum and selenite are found, but no great abundance of it.

Higher up clay bands vanish and coarse grits and gravels are seen which pass into conglomerates. The characteristic conglomerate containing red and green chert pebbles, which is so widely scattered throughout the Persian plateau, does not occur at the top of the series, but beneath the great mass of conglomerates. On the Konartakhta plain it outcrops in small ridges at the base of the high scarp dipping 30° W. S. W. It also appears in a small hill about one and-a-half miles south of Konartakhta dipping 5° S.W., while north-east of Konartakhta plain it caps the summit of the long hill running parallel to the river at Chorun. Here it dips at 15° S.W. and unconformably overlies rocks of the Fars series dipping 30° W. Outcrops of the same rocks occur on the hills one mile only to the north of the bridge over the Dáliki river.

In the high hills in the Mamaseni country north of the Shahpur river this red and green chert conglomerate shading into a coarse grit containing smaller fragments of the same rock is met with in precisely the same position dipping 42° W.S.W. directly under coarser conglomerate containing large pebbles of Nummulitic limestone. This

hill reminds one almost exactly of the hill overlooking the Kotal Malo. The Bakhtiyári beds form a synclinal basin, and on two sides of the hill at all events the strata are scarped passing down into the Fars beds. On the southern bank of the Shahpur river the red chert conglomerate was found dipping 30° S.W. lying unconformably on almost vertical beds of the Fars series. Fig. 1 shows the relation of the two sets of beds in the latter locality.

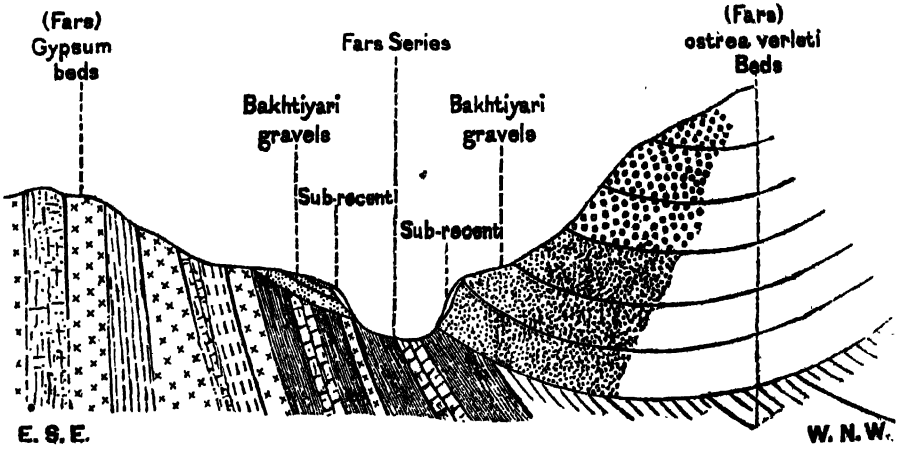

Fig. 1—Sketch Section on the Shahpur river (somewhat diagrammatic).

It is evident that the chert conglomerate is by far the most widely spread of the various beds in the Bakhtiyári series in spite of the fact that the thickness of the band is inconsiderable, hardly more than 10 feet and often less.

It seems that it represents a constant horizon. It is exceedingly hard, and to some extent no doubt it owes its preservation to this circumstance. I cannot, however, think that the wide distribution of this bed is without further significance than this, or that, except in special localities, previously overlying beds have been denuded down to the resistant chert conglomerate. Rather it seems that the chert conglomerates, gravels and grits correspond to a special period of flood in the ancient rivers of Persia, and at this period the deposit of the rivers far exceeded their ordinary limits. The very coarse conglomerates which succeeded them and which invariably

form the tops of the series probably were deposited in or near the rivers themselves. The period of their deposition doubtless corresponds to a period of gradual uplift and compression.

Both to the north and south of the Kamárij plain conglomerates of large limestone pebbles occur. In the former case at the entrance of the pass called Tang-i-Turku the conglomerates are about 1,000 feet in thickness and form a sharply folded synclinal lying upon the basal gypsum beds of the Fars series, and possibly faulted against them. South of Kamárij the conglomerate forms steep hills, and although the dip is horizontal they may belong to the Bakhtiyári series. On the other hand they may be more recent gravels, and in this connection I may remark on the presence of sub-recent pebble deposits high up above the present river level in many places. It was at first difficult to distinguish between these and the Bakhtiyári conglomerates, but their horizontal bedding united with the fact that it is often possible to find pebbles of the older conglomerates contained in them generally is a sufficient indication of their age.

To return now to the Fars series. After leaving them at the Kotal Malo dipping 30° to the N.E. they are not again seen until one meets them at Chorun dipping 30° W. underlying the Bakhtiyári beds as stated. From this point a continuous section of them is exposed up to the Kotal Kamárij, amounting to some 10,000 feet. The dip rapidly increases, and by the time the foot of the Kotal Kamárij is reached they are almost vertical. The character of the beds is the same as observed on the road between Dáliki and the Kotal Malo.

Soft greyish sandstones.
Soft red clay with numerous veins of gypsum.
Indurated blue clay.
Red clay containing great veins and masses of gypsum.
Grey sandstone.
Red clay.
Grey sandstone.
Hard marl.
Red clay.

Sandstone.
Soft blue clay.
Limestone band with echinoids.
Indurated clay.
Blue clays with beds of limestone.

These alternations are characteristic of the whole. The sandstones and various bands with which they alternate are generally not more than 10 feet in thickness, but sometimes, and more particularly with the clays, one gets continuous thicknesses of 100 feet or more of the same rock.

At the Kotal Kamárij we get a gradual passage down from the blue and pale grey clays of the plateau division into the gypsum beds, thick beds of gypsum of a thickness of 10 feet separated by clays with bands of argillaceous fissile limestone. Finally, bed after bed of gypsum practically vertical and striking north-west and south-east are passed over on reaching the top of the kotal.

The sketch section in Plate I indicates how the beds turn over, the bend being not a persistent one, but only one of a series of sharp contortions as it is plain that the beds turn over again on themselves, and are probably repeated in a series of folds, judging from their behaviour where seen in other localities. This repeated folding of the basal gypsum beds is very common, wherever they occur, and is due to the soft plastic character of the gypsum beds which has caused them to yield to the pressure.

It is not probable that the later beds which I have called the plateau division of the Fars series were ever deposited regularly over the basal beds in every area where the latter are exposed. The wide distribution of the latter seems to prohibit the supposition. It is more likely that the basal gypsum beds represent the deposit of a widely spread sea of the European Schlier period, and towards the close of it earth movements occurred which considerably limited the sea and turned much of the gypsum area into dry land.

Bordering the Kamárij plain on the western side they form a characteristic series of irregularly contoured, strongly coloured hills,

the red colouring of the iron-containing beds varied repeatedly by the white of the gypsum bands.

In these hills are various large deposits of rock salt of excellent quality. It occurs with absolute irregularity, not in regular beds, and seems to penetrate the gypsiferous and sedimentary beds as strings or veins. The mode of occurrence does not favour the idea of deposition from the bed of an ocean in the course of evaporation; hence it can only be connected in some way with volcanic activity. The exact mode of formation does not seem quite clear, but there seems no reason why one should take exception to a hypothetical subterranean magma containing chloride of sodium; that the saline injections must have been more or less contemporaneous with the marls and gypsum beds must, I think, be conceded, as one cannot consider the salt as being other than a manifestation of the same phenomena which have resulted in the formation of gypsum. Salt does not seem to be very common in this part of Persia, but its occurrence in these beds is interesting in relation to the greater quantities which occur in beds of tne same age near Lake Urmi in Northern Persia.

The great mountain range known as the Kuh Saláb, which separates the Kamárij plain from that of Kázrun, consists of an anticline of Nummulitic limestone whose general direction is north-west and south-east. To the north in the Tang-i-Turku the strike bends round to the north-east, and the range dies away against the basal gypsum beds of the Fars series. At this point the dip of the Nummulitics is no more than 5°, but it gradually increases to 30° which is the general angle of dip on both sides of the range. The topmost beds are scarped on the Kamárij side of the range, while the descent into the Kázrun plain is by long dip slopes cut into by enormously deep and narrow chasms. The road through the Tang-i-Turku practically goes along the boundary between the Nummulitic and the Fars series; beds of gypsum are found not 12 feet away from the Nummulitic limestone, and the gypsum beds exist as a discontinuous fringe along the base of the Nummulitic range on the eastern side of the Kamárij plain.

The Nummulitic limestone is throughout massive, of a buff or pale

grey colour, with often a yellowish or even bright reddish brown tinge on weathered surfaces. As a rule it is unfossiliferous, but beds of nummulites, whose characters are insufficiently indicated for determination, are met with, and occasionally fragmentary remains of *Pecten* and other mollusca. The rocky hillsides are covered with numerous shrubs or small trees of Tragacanth.

Kázrun lies in a synclinal plain between two ridges of Nummulitic limestone. This is the ordinary geological structure of the country. The upper beds are scarped on the north-east side. The character of the limestone is precisely like that of Kuh Saláb. Nummulitic bands are occasionally seen.

The range is a lofty one running up to over 10,000 feet. It is cut through by the magnificent gorge of the Tang-i-Chaku through which the Shahpur river runs. On the smooth precipices bounding the walls of this gorge are a series of carvings made in honour of King Shahpur.

Forming groups of low hills on the north-eastern side of the Kázrun plain are the basal gypsum beds of the Fars series. Here and there they are exposed in excavations or hollows beneath the recent alluvium.

The Fars beds are interrupted by a broad stretch of alluvium which runs up into the Tang-i-Chaku, and forms low hills of conglomerate on the other side of the Shahpur river which are probably recent, but on the other side of this they are strongly developed, both to the east and west of a prominent ridge of limestone with concretionary flints which is probably Nummulitic. This limestone ridge dips 20° W. and forms a very pronounced scarp on its eastern side, against which the Fars beds are folded and possibly faulted. I saw them dipping steeply to the east not far away. On the western side of this Nummulitic ridge, the Fars beds consisting of rock-gypsum, marls, sandy limestones, argillaceous limestones are lying without any appearance of unconformability on the limestone. Some of the limestone bands contain shells, and in appearance are very like those seen in the basal Fars beds at Chinar Rahdar (page 73). These may belong to the Urmi series. They form a

series of low rounded hills hardly rising more than 200 feet above the general ground level, and cut up by valleys to an unlimited extent.

This type of scenery is developed as far as the eye can reach to the west and north-west, and it continues right along to Rahdar, where on the Shahpur river a splendid section of these beds joins the Bakhtiyári series. (See above p. 65 and fig. 1.) In effect the beds are a direct continuation of those exposed in the Kotal Kamárij ; only the strike is to the north-east instead of to the north-west. There is evidence of considerable folding in the river section of the basal gypsum beds. As a rule the beds are dipping very steeply, sometimes almost vertically. Near the junction the *Ostrea verleti* beds dipping at 80° S. E. pass up through vertically dipping beds into those in which the dip is reversed and is 80° N. W., all of these beds being rock-gypsum. The beds are of the usual type, shales, fissile limestones, and shelly limestones in which the shells are massed in great numbers and do not weather out recognizably, but exhibit black sections on partly broken surfaces. On nearing the Bakhtiyári junction the plateau division of the Fars series is well exposed. Great thicknesses of red and blue clays and fossiliferous marls with *Ostrea verleti*, containing also a species of *Ostrea* identical with one out of the marine beds of the Hinglaj series, occur, with occasional gypsum bands and very thin shelly limestones, all dipping at 75° to the west-north-west.

The unconformity between these beds and the Bakhtiyári gravels has already been noticed. It is here very striking. Much of the Fars series is evidently not represented here, being covered by the Bakhtiyáris which, as has been stated, are dipping about 30° W.S.W. where I saw the junction. Since, however, the Bakhtiyári beds form a synclinal basin, the direction of dip varies gradually as the outcrop is followed round either side. In places the dips of the two series correspond so nearly as to give a false appearance of conformity.

There is a good deal of recent pebbly conglomerate, lying on the cliffs 60 feet above the river where the dip can be made out ; this is

horizontal; it can also be distinguished from the Bakhtiyári conglomerate by the fact that rounded pebbles and boulders of the latter are often seen in the recent deposit.

As has been already remarked, a lofty range of Nummulitic limestones bounds the plain of Kázrun on the north-east, known as the Kuh Dashtak. This is cut through by the Tang-i-Chaku which leads us into a narrow synclinal valley, which is blocked at the south-eastern end around the small village of Gao Kuh i Shak by a mass of Fars gypsum hills which dip at about 45° overlying the Nummulitic limestone. Presently beds of limestones and gypsum bend up and are seen dipping steeply to the N.E.

The ordinary caravan route to Shiraz leaves the Kázrun plain from its south-eastern end above the Famor lake, by the precipitous pass known as the Kotal Dukhtar or the Pass of the Young Girl. The traveller on approaching this wonders how his riding animal is going to find a path up what looks like a vertical wall of rock. Narrow ledges, however, have been enlarged to afford a foot hold for a path, which though used by generations of Persian charvardars in the past, still remains an awesome undertaking for the timid rider.

At the top of this pass we find ourselves in another narrow alluvial plain, known as the Dasht-i-Barm or Plain of Oaks, on account of the magnificent oak forest with which most of it is covered.

Another pass, the Kotal Pir-i-Zán or the Old Woman's Pass, takes us over into the Dasht-i-Arjan plain. A narrow band of the Fars series is passed consisting of beds of gypsum, buff coloured, fissile, argillaceous limestones, and blue shales.

As usual this range is an anticline. To the north-west, however, the range is split into two, so that the crest of the anticline lies in a valley. It is this portion which is represented in the section (Pl. I). On both sides of the valley a thick bed of shales is exposed underlying massive Nummulitic limestones. The shales are underlain by limestone which has been cut through by a narrow river gorge having absolutely precipitous sides.

I am unable to say with certainty whether these shales and lower

limestones are Nummulitic or Cretaceous. As I found no hippurites in the lower limestone in the places where I examined it, it may provisionally be regarded as Eocene, although one is instinctively reminded of a very similar bed of shales in the Bakhtiyári mountains, which is Cretaceous.

The Dasht-i-Arjan plain is entirely surrounded by hills of Nummulitic limestone, which are in places quite precipitous. It is quite bare of trees and most of it is swampy. At its northern end is the village and telegraph office, and out of the limestone rock here issues a powerful spring.

The caravan route crosses a pass east of Dasht-i-Arjan. Here the Nummulitic limestone is dipping only 5° E. and in a very short time gives place to the basal gypsum beds of the Fars series, which cover an extensive area stretching between the Shiraz plain and Dasht-i-Arjan. In fact, with the exception of a recent alluvial plain around the caravanserai of Khaneh Zinián, the alluvium around the river, and possible small outcrops of the Bakhtiyári gravels, the whole of it may be referred to this portion of the Fars series.

These beds occupy as usual a series of low hills hanging on to the two tall ranges of Nummulitic limestone, one running north-east from the Shiraz plain and the other striking north-east and south-west from Dasht-i-Arjan. Many sections are visible showing the sharp and frequent folding to which these beds have been subjected. It is, however, quite useless to represent these in a section, as although we can be certain that folding has taken place, the lithological changes in the beds succeed one another with such rapidity that one can never be sure whether one is looking at a different horizon to one which we have just passed or the same. Further, the dips do not help us as the beds are in many cases manifestly folded over on themselves.

A careful study of the slopes and the lithological character and thickness of the beds exposed in the hills between the Chinar Rahdar caravanserai and the Nummulitic range to the north of it has led me to consider that the following represents a continuous sequence of

beds in descending order representing a thickness of some 500 feet, which is repeated more than once and probably several times in the whole outcrop:—

Bands of rock-gypsum some 40 feet in thickness, dipping 70° N.E.
Greenish gypsum.
White or pale coloured shales.
Red clay band with gypsum,
Pale coloured limestone.
Greenish arenaceous shales.
Pale coloured limestone.
Soft sandy shales.
Limestone, 60° N.E.
Gypsum bands.
Shelly limestone.
White or pale coloured fissile argillaceous limestone.
Red sandy looking limestone without nummulites.
Yellow sandy looking limestone with nummulites.
Massive Nummulitic limestone.

It seems possible that the pale coloured reddish or yellowish limestones overlying the massive Nummulitic limestone may be of the same age as the Clypeaster beds (Urmi series) of Shalil in the Bakhtiyári mountains (page 22) and may be unconformable to the mass of the Nummulitic limestones, being in fact burdigalian in age.

The basal gypsum beds are dipping steeply to the north-east at a point so close to the south-westerly dipping Nummulitic range, that it seems certain therefore that there was a considerable unconformity between the two series.

All these beds are dipping steeply at angles of from 60° to 70° either to the north-east or south-west, but further to the south-west the dip diminishes, and in the river beneath the caravanserai at Chinar Rahdar a series of blue shales and limestones with gypsum are dipping only 15° N.E.

I need only refer to certain other beds of this series representing doubtless higher horizons, which I met at different places in this locality. A limestone very hard and compact and made up of fragments of mollusca, which do not, however, as a rule weather out so as to be recognizable, is very frequent. The shells usually appear as black sections on a broken surface of the rock. The same rock can be recognized in the Bakhtiyári mountains. Another shelly band is crowded with *Clausinella* sp. *cf. amidei* Sacco. A limestone band containing the same species of *Ostrea*, which is so common in the Gaj formation in India and hitherto known as *Ostrea multicostata*, is occasionally found. A bed of slaty shales is met with.

I have referred above to the Bakhtiyári gravels. Huge blocks of the red chert conglomerate, often passing into a grit in which small red and green chert grains are plainly visible, are to be seen fairly frequently on the road from Khaneh Zinián to Chinar Rahdar, and on the slopes of the Nummulitic range on the side facing Shiraz. These undoubtedly represent fragments of an almost entirely denuded bed of the Bakhtiyári conglomerate, and in one place, not far from Chinar Rahdar, this bed was actually found *in situ* capping a hill consisting mainly of Fars rocks. This chert conglomerate was also found *in situ* on the hills above Dasht-i-Arjan.

It will be convenient here to refer to the last appearance of this rock, which I have to record in this part of Persia. North-east of Shiraz on approaching Zarghun several low hills are made of a conglomerate of red and green cherts set in a highly compact calcareous matrix. The dip is slight, and there seems no doubt that this must be referred to the Bakhtiyári series.

The town of Shiraz lies in an alluvial plain formed in a synclinal of Nummulitic limestone. I examined the hills to the north-west, but found in them no identifiable fossils. Dr. W. T. Blanford, who travelled up to Shiraz from Kermán past the salt lake called the Daria-i-Mahalu, has noted the formations he met with to the south-east of Shiraz (**23**, pages 494, etc.). They seem to be entirely Nummulitic.

Taking the Ispahán road from Shiraz, massive Nummulitic limestone is seen dipping to the south-west. The dip is reversed before crossing the final range separating us from the Bajgah plain. Between these two points frequent beds of shale and yellow or reddish sandy limestones are interbedded with the grey massive limestones. These weather to a red soil, which conceals the rock between the outcrops of massive Nummulitic limestone. The dips are seldom more than 25°. On the other side of the Bajgah plain the Nummulitic limestone is again dipping to the south-west. As already mentioned (p. 74), on the edges of this last range are low hills of the red Bakhtiyári conglomerate, while between Duda and Zarghun, on the eastern side of the road, the hills are of hippuritic limestone. At Zarghun we enter upon the great plain of the Marv-Dasht. The river Band-i-Amir waters it, and promotes during certain seasons of the year a luxuriant growth of cultivated crops. There is a considerable thickness of fine alluvial clay. The detached hills are all of hippuritic limestone, as is also the great range, at whose foot nestle the splendid ruins of Persepolis. Here in places the limestones are crowded with foraminifera bearing, according to Mr. E. Vredenburg, a relationship to Orbitolina, which points to a cenomanian age at latest for this portion of the range.

CHAPTER II.

TURKISH ARABIA, ARABISTÁN AND THE BAKHTIYÁRI COUNTRY FROM MOHAMMERAH TO SARKHUN.

High as the Bakhtiyári country ranks in scenery and climate, the approach to it from the Persian Gulf can only be described as one of the dullest monotony. Steaming up the Shatt El Arab to Mohammerah, the banks on either side abound in date gardens, while villages and houses here and there give some interest to the journey; but on the Kárún river right up to Ahwaz even the date palms have disappeared, and a dreary alluvial plain stretches away as far as the eye can reach, quite bare of vegetation or at most with only a few tamarisks and salt-loving grasses of low growth.

The heat which is experienced here during eight months of the year passes description. At Mohammerah it is of a damp, oppressive kind, while at Ahwaz it is accompanied by a dry hot wind, often at a temperature of 130° F. In the winter months it not unusually freezes at night.

As far as Ahwaz, the sole geological formation met with is the recent Mesopotamian alluvium. I can add nothing to the admirable account which M. de Morgan[1] has given of the extent and rate of growth of this deltaic deposit or to the various data he has collected which go to prove the former extension within historical times of the Persian Gulf. A summary of our knowledge on these points is given on page 57 of the present paper.

At Ahwaz for the first time low hills of a reddish sandstone come into view, belonging to the Bakhtiyári series. They are dipping some 25° N.E., and hardly attain an elevation of more than 300 feet. The range is cut through by the Kárún river which here forms an extremely narrow channel along which the river flows in a series of rapids between rocky walls, which jut out into the river, and form what is known as the Ahwaz *band*, and which renders continuous navigation between Mohammerah and Shushtar an impossibility. The Ahwaz hills can be traced with slight interruptions south-eastward into the Zeitun hills near Behbahan, and north-westward up to the Hamrine range, the formation being everywhere remarkable for the reddish colour of its sandstones. This is due to reddish chert, which, occurring either in small grains as here, or as large pebbles in conglomerate beds, forms such a characteristic feature of certain beds of the Bakhtiyári series wherever found.

The regular north-west and south-east folds of the strata, in this country as in other parts of Persia, enable us to follow the formations with some degree of ease, and even to predict broadly what rocks may be expected to exist in a given locality.

The road from Ahwaz takes us across another open plain, broken

[1] J. de Morgan : *Mission Scientifique en Perse*, II, 284; III, 1, 124.

only by a few low mounds of the Bakhtiyári sandstone, to Alwani, about 13 miles south of some naphtha springs. In summer everything here is parched and bare, and the heat is unbearable.

We have now left the plains, and although the hills for some distance are of inconsiderable elevation, both climate and scenery are a relief to the wayfarer, who has been traversing bare arid tracts beneath a blistering sun. The beds first met with belong clearly to the basal gypsiferous division of the Fars series dipping gently south-south-west (Sketch Sections Pls. II and III). Beds of gypsum alternate with limestones, some of which are sandy while others are fairly pure. Amongst the latter are thin beds crowded with fragments of shells, which are unidentifiable, as weathering only exposes sections of the shell, which are often quite black. The appearance of these thin shelly limestone bands is precisely like that of similar beds met with in the same part of the series at Chinar Rahdar, Khaneh Zinián, and other places west of Shiraz. A band of thinly-bedded fissile argillaceous limestone was seen.

The dip is reversed and the beds dip gently to the north-west. This is approximately on the strike of the naphtha springs. The general height of these hills is some 500 feet above the plain.

We now seem to pass up into higher beds, which seem to correspond in character with the second or plateau division of the Fars series. Beds of blue marl appear, and after one or two intercalated beds of rock-gypsum have been met with, this mineral ceases to be seen in that form and only exists as thin veins penetrating the marls or clays. Thin beds of shelly limestone, readily breaking into pieces at a blow of the hammer, remind one of the beds met with between Dáliki and Kamárij on the Bushehr-Shiraz road. The dip is seen very well and there can be no doubt about the general conformability of all the beds to one another. Scarp succeeds scarp of which dip slopes are at angles of 20° N.E. and N.N.E. Beyond this, beds of sandstones appear, which higher up in the series become more frequent. Some of these are hard and massive, others are soft and crumbly and rather thinly bedded.

About·13 miles from Alwani, the main summit of the range is crossed, in a short kotal consisting of sandstones intercalated with red clays. The dip has increased to 35° E.N.E. and the descent into Joru is through low hills where sections of indurated clays and sandstones similarly dipping are occasionally exposed. It would be wearisome to mention in detail each bed encountered in this vast section, and in many cases impossible owing to insufficiency of the exposures. Suffice it to say that for many thousands of feet indurated marls and clays of a blue or red colour alternate incessantly first with limestones and then with sandstones and grits.

It will have been observed that the whole of the range of hills just passed forms a shallow anticline, of which the highest beds, whose general character can leave us in no doubt about referring them to the Plateau or *Ostrea verleti* division of the Fars series, have been denuded at the south-western end. When we reach Joru we have seen the last of these Plateau beds, although the underlying gypsum beds are met with for more than 50 miles further inland. It is evident that the great marine basin in which the Fars series was deposited had become much contracted in extent before the *Ostrea verleti* beds were laid down.

Joru lies in a plain composed of recent deposits, which form several low hills where sections of a coarse conglomerate are exposed. Joru itself lies on the top of one of these gravel hills, at an elevation of 1,500 feet above the sea.

On the other side of the Joru plain rises a range consisting of the characteristic basal gypsum beds. As is so often the case, these beds are sharply folded, and there seems to be at all events one sharp anticlinal fold, as gypsum beds dipping vertically are twice passed over and the hard limestone with black shell sections, also dipping vertically. These limestones present a most curious appearance. They stand up like walls some 10 to 20 feet high and some 1 to 2 feet thick, right above the softer beds of shale which have offered no resistance to the weather.

The road passes out of these gypsum hills at a place known

as Chashma Raughan, and for some miles lies over another of the flat expanses covered with recent deposit which are such a common feature throughout the Persian plateau. About 4 miles away from Chashma Raughan several low hills rising to about 200 or 300 feet above the plain are met with composed of a conglomerate which is probably recent. The contained pebbles vary in size from that of a hen's egg up to a man's head. Some 6 miles from Chashma Raughan this gravelly conglomerate rests on beds of the gypsum series dipping no more than 5° N.E.

The most prominent feature now is a range of hills rising to nearly 3,000 feet above the sea having a very red colour, which alone would dispose us, viewing them from a distance, to the opinion that they belonged to the Bakhtiyári series. A close examination of the rocks of which they consist shows that the highest beds exposed are of the red chert conglomerate, dipping 35° N.E. and forming a very precipitous scarp immediately south of and on the side of the range remote from the village of Ali Khurshid. The conglomerate contains, besides pebbles of red and yellow chert, also older limestones, either Nummulitic or Cretaceous, quartz, and an ancient quartz conglomerate. This range is cut through by the Balwas river which forms a rather deep gorge, and on the other side only lower beds of the Bakhtiyári series are exposed, which gradually seem to die out against the gypsum beds; while looking along towards the range on the south-east, the characteristic red colour of the Bakhtiyári beds was not observed. The gypsum beds in fact pass almost completely round the hill which terminates the red sandstone range.

The red conglomerates pass down into regular red clays, and then into red sandstones. The red sandstones are well exposed in the bed of the Balwas river. Plate VI exhibits a section of the red sandstones of the Bakhtiyári series with interbedded clay bands; all of them unconformably overlain by a recent gravel deposit. These beds, gradually diminish in dip from north-east to south-west, being 35° N. E. over Ali Khurshid and only 10° near their junction with the gypsum beds, which have an even smaller dip to the

north-east. At Ali Khurshid, however, the gypsum beds are very folded into anticlines with vertical sides. Two of these folds are clearly seen at Bagh-o-Malek.

Thus, as shown in the section, the gravels of the Bakhtiyári series are dipping under towards the gypsum beds. There may be thrust faulting and the gypsum beds may have glided over the Bakhtiyári series, but it seems also quite probable that the Bakhtiyári beds are the remains of a Pliocene river deposit laid down quite unconformably on the gypsum beds which had previously been subjected to folding and denudation. In any case the great unconformability between the two series is manifested most clearly in this section.

The gypsum hills here as elsewhere exhibit the characteristic irregular contours, and the peculiar colouring. They nourish a most remarkably rich xerophytic flora, consisting of innumerable species all exhibiting marked xerophytic adaptations and in very marked contrast to the flora of the Nummulitic and Cretaceous rocks very soon to be encountered.

On the other side of the alluvial plain, at one margin of which lies the village of Ali Khurshid, rise hills of conglomerate which separate the Ali Khurshid alluvial plain from that of Kala Tul. This conglomerate is composed almost entirely of pebbles of the older limestones and the dip is 20° S.W. It rests unconformably both on the gypsum beds which border the Ali Khurshid plain and on the Nummulitic limestone of the Kala Tul plain. These conglomerates seem to be the same which have been found overlying the red chert conglomerates and probably belong to a later stage. To the south-east the gypsum beds are clearly seen overlying Nummulitic limestone, of which there is an inlying anticline surrounded by gypsum beds, detached from the main range.

From now on, the Nummulitic and Cretaceous rocks are the most prominent geological formation, and the massive limestones which run up to 12,000 feet in the loftiest summits completely dominate the scenery contrasting markedly with the comparatively low and gentle declivities which one has seen so far in the rocks of later tertiary age.

These later ertiary rocks, however, have by no means vanished entirely from the landscape. The basal gypsum beds of the Fars series have been folded in, generally very sharply amongst the Nummulitic and Cretaceous rocks, and are now found in the valleys between the lofty limestone ridges on either side.

The Bakhtiyári gravels lie unconformably on all the older rocks, and their greater degree of hardness and resistance to weathering agencies has resulted in their forming generally much higher ground than the gypsum beds do.

The folding and arrangement of these various beds can be better understood by reference to the accompanying map (Plate XVI) and sections (Plates II and III) than by detailed descriptions. I shall therefore make the latter only supplementary to the former.

At the further end of the Kala Tul plain the road passes through a range of hippuritic limestone in a narrow gorge traversed by a feeble stream, known as the Tang Nashelil. These Tangs or transverse clefts through limestone ranges are common in Persia. Often they are occupied by large rivers, which after flowing for many miles in a strike valley, containing possibly gypsiferous beds, suddenly break through a lofty range, and then resume their course along the parallel strike valley on the other side of the range. Sometimes the Tangs are dry. Their origin is of course to be traced to the period when the drainage of the country first began to be established, when the whole country was covered by the gypsiferous beds of the Fars series and before the excessive folding, which now prevails, had taken place. The rainfall adopted channels running straight down to the sea, which it deepened in proportion as the land rose and was folded. Strike streams occupied the troughs, and these cutting down faster through the softer marls of the Fars series beheaded some of the primary rivers and left their former channels in the course of ages high above the strike valleys, which had by now become the main streams. A few of the transverse gorges in this way dominated the rest, and usurped the task of conveying the drainage of the Persian plateau. But remains of former transverse valleys are to be seen at various

levels, according to the period at which they ceased to convey the drainage of the country.

After passing through the transverse gorge, the road for 7 or 8 miles passes between narrow cliffs, almost vertical on either side, and finally emerges into the broad Mal Amir plain.

In describing the beds that remain it seems most convenient to begin at the limit which my journey reached, that is the country immediately to the north of Sar Khun. This lies in a fertile valley at an elevation of some 3,500 feet through which a small stream flows in a rocky bed having precipitous cliffs of hippuritic limestone on its southern side and shaded by willows on its other bank. The Ispahan road ascends gradually at first over rounded hills covered with conglomerates of the Bakhtiyári series dipping steeply, and finally passes through a gorge into the mountain fastnesses of hippuritic limestone. It was at Do-poulan somewhat north of this that M. de Morgan rediscovered the locality for *Loftusia*, described by Mr. W. K. Loftus in 1855. The limestone where I saw it is destitute of determinable fossils and its age is only known by the occasional fragments of hippurites. I found a poor specimen of *Caprina* sp. Certain beds of this limestone contain flint concretions.

The ascent of the Gerrah range from Sar Khun displays a great amount of the red Bakhtiyári conglomerate overlying the massive hippuritic limestone, sometimes dipping steeply down in the same direction as the limestone, sometimes lying on the scarped edges of the limestone beds. Plate IV is an illustration of this. A journey through a richly wooded valley brings us to the summit of the pass between two lofty pointed peaks. These seem to be of Nummulitic limestone. On the other side of the pass, soon after beginning the descent, a considerable amount of a very hard compact calcareous conglomerate is exposed. This contains pebbles of hippuritic limestone and is directly overlain by Nummulitic limestone. It is therefore undoubtedly a basal conglomerate of Nummulitic age. It is dipping some 40° N.E. apparently, but doubtless turns up again along with the other beds on the northern side of the pass,

where, however, I did not observe it. The descent to Shalil is a fairly gentle one through oak forests. A good deal of the Bakhtiyári conglomerate is seen. Along the Shalil stream are frequent exposures of the gypsum beds. Overlooking Shalil itself on the north are precipitous cliffs of red Bakhtiyári grits dipping 30° N.E.

It is impossible to say anything very definite with regard to these gypsum beds here, but it is plain that they have been folded and squeezed enormously. Moreover, this folding has embraced the Bakhtiyári series whose grits, or at least beds which I assigned to that series, are dipping vertically in one place.

On the slopes of Maulwari immediately above the Ab-i-Bazuft, and not far from the last outcrop of the Fars gypsum beds, red Bakhtiyári conglomerates lie directly on Nummulitic limestone.

The Ab-i-Bazuft at the Maulwari bridge and for about two miles further down flows on the Shalil side of Maulwari, along the junction of the Fars and Nummulitic series, but then taking a sudden bend to the south it breaks through the whole thickness of Nummulitics exposed in the Maulwari range, and runs in a channel excavated out of a thick bed of blue shales and thinly bedded marls. This bed of shales I assign to the Cretaceous, although I found no fossils in it, partly on Mr. Loftus' authority who was led by its lithological affinities to Cretaceous beds elsewhere to class it as such, partly for the following reasons:—

1. Only a short distance away between Shalil and Sar Khun, there is no trace of this thick shale bed at the base of the Nummulitics, but instead there is a conglomerate. The inference is therefore that it belongs to the Cretaceous and was denuded before the Nummulitics of the Gerrah range were deposited.

2. It seems certain that this shale bed is represented at the Kala Madraseh, where it underlies Nummulitic rocks just as here, but over the Mal Amir plain it is almost certain that hippuritic limestones cover the shale bed, and if I am right in identifying the shales in the Kala Tul plain with the same band, there, too, they underlie hippuritic limestones.

That there was a considerable interval between the period of the hippuritic limestones and the deposition of these Nummulitic beds is certain, because in the limestones immediately above this shale bed is *Nummulites lævigatus*, a variety which weathers in a peculiar manner with tubercles on its external surface. The same nummulite is found in beds much higher up. These limestones are therefore of middle Lutetian age.

Most of these Nummulitics consist of thinly bedded limestones alternating with bands of shale, and are very different in general appearance from the Cretaceous limestones. These beds are dipping at angles varying from 25° to 30° N.E. On the summit of the ridge immediately overlooking Maulwari bridge I found some more nummulites in a rubbly limestone dipping about 30° N.E. This bed does not lie stratigraphically very much below the beds exposed in the Ab-i-Bazuft near the bridge. The latter are noteworthy as containing in a yellowish rubbly limestone numerous specimens of *Clypeaster* sp. *aff. depressus*, *Pecten cf. rotundatus*, and *Operculina complanata*. There is, however, no trace of nummulites in this bed. It seems to pass down directly into massive limestone, while above it is exposed a whitish sandy limestone, then a marl, then pale coloured shales which crop out from beneath the much folded beds of the Fars series. It is not likely that these beds can be assigned to an earlier date than the Upper Oligocene, and there seems no doubt that they are to be correlated with the limestones of Lake Urmi which are probably of burdigalian age ; I have referred to these and similar beds mentioned by Loftus as the Urmi series.

Beneath the blue marls a broad outcrop of hippuritic limestone is exposed, the whole forming an anticline, whose southern slope does not extend to the Dehdiz summit. Nummulitic limestones occupy this summit, and although for great distances the road goes through oak forests where no rocks are visible, on the steep hill slopes leading down to Dehdiz a rubbly limestone is exposed, passing into a cream coloured limestone crammed with nummulites, which, however, I was unable to extract in a suitable condition for identification.

The Nummulitic beds form probably a couple of folds beneath the Fars and Bakhtiyári series, which occupy a broad outcrop of six or seven miles.[1] A rather high hill between the Rikat valley below Dehdiz and the Kárún river consists of the Bahktiyári gravels dipping 60° S.W. on the north side of the hill, but bending over into the river Kárún further south. Further to the west, the two folds of the strata are clearly seen. They are also far sharper than is the case at Dehdiz, and the gypsum beds are squeezed into a very narrow outcrop, not exceeding a mile in width, while in the second fold I find no distinct indication of their presence.

In the Nummulitics near Godar bridge occurs a dark coloured limestone with a strong bituminous smell.

In the hill just next to the bridge a perfect junction is seen between the Nummulitics and the Fars series. (See Plate XI.) The junction occurs just on the crest of an anticlinal, from which the Fars beds have been denuded and an inverted sequence obtains. The limestones are dipping 80° N.E. They are compact and pale coloured. Besides fragments of nummulites I found a *modiola*. They pass down into fawn coloured rather fetid limestone and then into fawn coloured shales. A thick bed of gypsum bounds this dipping 80° S.W. The dip is therefore not quite concordant with that of the limestone. Below it are a succession of red and blue clays with harder shaly limestone bands from 6 inches to 1 foot thick between, another gypsum band, more red and blue clays, impure limestone bands, red sandy beds, soft red clay, clays containing veins and patches of gypsum, grey gritty sandstone. The hill between the Kárún valley and the Sultani ravine, cut through by a narrow gorge commanded by an old fort called Kala Madraseh, consists of a half-fold of Nummulitic rocks. Between these and the hippuritic limestones is a thick bed of blue shales and fissile limestones, which seems to be identical with the

[1] Owing to a mistake of the lithographers, which, on account of my absence from Calcutta, has remained uncorrected, the gypsum beds between Dehdiz and the Karun river appear to pass into the Nummulitics whereas they really overlie them. Also north of the Karun river gypsum beds are shown lying on the Bakhtiyári series, instead of the reverse order.

shales between Maulwari and Dehdiz which I have assigned to the Cretaceous. The hippuritic limestone, containing flint concretions, and fragments of hippurites and ammonites, occupies most of the Kotal-i-Sultani. It, however, bends over at the top, and the blue shales are again exposed forming a shallow syncline in a stretch of flat ground between that and the descent into the Mal-i-Amir plain. The shale bed again dips under to the south-west and disappears under bed after bed of hippuritic limestone which forms the steep descent of the Mush Kuh into the Mal Amir plain. These beds are dipping 45° S.W. high up, but towards the base of the descent it has decreased to 15° S.W. The shale bed is probably exposed in various places in the Mal Amir plain accounting for the marshy character of much of the ground. A lake which exists in the middle of the group of hills bordering the Mal Amir plain on the south is probably due to the same reason.

There are several folds throughout the extent of the area which I have here mapped as Cretaceous, and it is possible that beds of Nummulitic age are exposed throughout these ranges. As I have not been through them I cannot speak with any knowledge on the matter. As, however, at the entrance of the Tang Nashelil there are sharply folded beds of hippuritic limestone overlying a bed which I regard as equivalent to the shale bed of the Cretaceous which I have previously mentioned, there is evidently a considerable thickness of Cretaceous limestone to be accounted for before coming to Nummulitic beds. The section in Plate II will make this plain. The dip of the fold is very distinctly towards the north-west, and going along in a south-easterly direction one sees lower and lower beds exposed, while the topmost limestones have been denuded until a mile or so away much of the section of the hill consists of the shale and fissile limestones mentioned.

CHAPTER III.

'OMAN AND TRUCIAL 'OMAN.

On reference to a map it will be seen that 'Omán embraces the whole of the south-eastern corner of Arabia, stretching also

along the coast in a south-westerly direction up to some distance beyond the Kuria Muria islands until it joins the so-called Hadramaut. The greater part of the peninsula of Ruus El Jibál and the coast running along first south, then west, to the peninsula of Qatar is known as Trucial 'Omán or the Pirate coast. This is a vast area of which I can only claim to have seen a very small portion myself, while that seen by other observers is equally restricted. When further it is realized that the whole country remains as yet unsurveyed topographically it will be understood what my difficulties have been in obtaining a correct idea even of the portion which my limited time enabled me to visit. Still as the hardships and dangers of travel in Arabia make it unlikely that any geologist will be able to visit 'Omán again in the near future, it is worth while making the fullest use of such scanty material as we at present possess. Under these circumstances, therefore, I need hardly apologize for the provisional nature of the geological colouring of 'Omán in the map in Plate XVII. It does no more than attempt to give a general idea of the main formations met with. When, for instance, the mountain ranges of Jebel Akhthar are coloured as Carbo-Trias (a designation which in itself is a confession of ignorance), it is meant that we may feel fairly sure that the whole of these ranges is composed, speaking generally, of the various types of limestone assigned to that age, although one would be quite prepared to find patches or even large areas of the intrusive basic series, of whose existence we are at present just as ignorant, as we are of how far rocks of Cretaceous or Eocene age run up into the great Carbo-Triassic ranges, or to what extent their place on the landscape is taken by sub-recent accumulations or by the intrusive basic series just mentioned.

The following account deals with my journeys in the neighbourhood of Muscat and up into the interior, right in the heart of the great limestone ranges, and also in the peninsula of Ruus El Jibál along routes which I was the first European to traverse. Associated with this is such geological information as I have been able to extract from various papers or unpublished manuscripts by various

authors, of whom the chief are Wellsted and Miles. This is, however, generally inadequate in character, and trifling in amount. Of more importance are the specimens and brief notes left by the late Dr. A. v. Krafft and Mr. R. D. Oldham. Finally, where relevant, I shall make brief allusions to Carter's published account of his voyage along the 'Omán coast although the deposits which he met with will be referred to according to their age under the heads of the epoch to which they belong.

The town of Muscat,—Maskat according to the general orthography adopted for Indian names,—lies within a small inlet surrounded and overshadowed on three sides by dark coloured igneous rocks, which contain for the most part serpentine, and abundant, often large crystals of lustrous diallage; this type is very widely scattered throughout the area where the igneous rocks of 'Omán are exposed and may be known as serpentine rock. Forming thin veins in the joint planes is a great amount of friable magnesite.

The dip of these rocks is seldom determinable, but in some places it can be seen to be about 30° N.W.

The Muscat serpentine extends for a distance of six miles along the coast in a south-easterly direction to Bandar Jissa, where it is unconformably covered by yellow and buff coloured sandy limestones containing *Nummulites atacicus*, *Nummulites globulus*, *Assilina granulosa*, and the echinoids *Schizaster* sp., *Moira* sp., *Echinolampas* sp., *Brissopsis* sp., and *Prenaster* sp. aff. *oviformis* Dunc. and Sladen, along with several badly preserved casts of mollusca. This fauna points to a lower lutetian age for these beds, corresponding to the Egyptian Lybian series, and to the Laki series of Sind and Baluchistan. *Prenaster oviformis* is assigned to the Ranikot series in Duncan and Sladen's memoir, but as stated by Mr. E. Vredenburg, those specimens came from a locality where the Laki series is exposed in contact with the Ranikot, and Duncan's species is really of Laki age. Mr. R. B. Newton[1] mentions the occurrence of

[1] R. B. Newton: "The Tertiary Fossils of Somaliland." *Q. J. G. S.*, LXI, p 158 (1905).

a *Campanile* resembling the Somaliland forms, which he found in a collection of fossils from Bandar Jissa. A pebble bed 50 feet thick lies at the base of these limestones.

The serpentine outcrop runs without interruption along the coast in the other direction to Darzeit, where it is overlain by Nummulitic rocks, at whose base is a bright red lateritic rock, similar to a formation which is common in Baluchistan (see page 97) and which points to continental conditions probably immediately succeeding Cretaceous times. As at Bandar Jissa, a pebble bed lies at the base of the sedimentaries on the coast, and above it are very sandy limestones, becoming more calcareous higher up and containing numerous badly preserved fossils and nummulites. Richly variegated gypsiferous clay bands occur about half-way up the hill, and above this a compact yellowish limestone. The whole sedimentary formation is here as much as 400 feet thick. It is continued throughout the remainder of this small range, which runs from Darzeit in a south-west direction, bounding the Ruwi plain and terminating near the village of Lutayi. The beds roll about irregularly without any high dips. At that point of the hill range, which comes nearest to the fort of Baital Falaj, the pebble bed and the laterite are underlain by a buff coloured limestone with veins of calcite and gypsum, which may possibly be Cretaceous, although I found no fossils in it. Associated with the laterite are red clays. The conglomerate is some 10 feet thick and contains pebbles as large as an orange. The rest of the section contains limestones similar to those at Darzeit, gritty at the base and purer above. Nummulites also occur here.

Resting on the edges of the hills is a false bedded, loosely compacted sandstone, which is cut through by a recent watercourse, and is in places overlain by a sub-recent or recent conglomerate. This is probably contemporaneous with the miliolitic formation.

Taking the road going west-south-west from Matra, we emerge after about a mile and-a-half from the serpentine hills into an open plain with but few outcrops, which separates us from the small village of Ruwi. This plain is bounded on the north-west

by the range of hills, which consists chiefly of the Eocene beds, while on the south-east the serpentine is continued. Near the fort of Baital Falaj occur various rocks rising only a few feet above the surface belonging to the 'Omán series. These are continued, striking about west-north-west to east-south-east, until they meet the Eocene hills. They consist of rather crystalline limestone with numerous quartz veins, and beds of chert or jasper. The latter are sometimes three or four feet thick, and are grey or greenish coloured or red. The red cherts are generally thinly bedded and cleave easily, while the others are more massive. These beds seem at this place to be separated from the serpentine by a sort of soft clay, dipping apparently like the limestones and cherts at a very high angle. This may be a product of decomposition of some sort.

On the other side of the plain, as we approach Ruwi, some low isolated hills rise up, composed of hornblende schist, of which the planes of foliation are dipping steeply to the north-east. These belong to the Hatát series and are provisionally considered as Archæan in age. To the south-east on the same strike and only a few hundred yards away, beds of the same character are seen in contact with the limestones of the 'Omán series, which are striking in nearly the same direction. This outcrop of the Hatát series almost presents at first sight the appearance of being interbedded with the limestones. The schists, however, do not continue to the south-east, but are entirely covered up by limestone. It seems evident therefore that denudation has at this spot partially exposed the old Archæan sea floor on which the palæozoic strata were deposited. From the point where the Hatát schists crop out, a small wadi runs to the south-east. On my right hand side, as I ascended it, rose the range of the 'Omán limestones dipping at angles varying from 45° to 55°, while on my left hand were the serpentine hills dipping in the same direction as the limestone, the two formations being seen *in situ* within a few feet of one another. The igneous rock near the junction is more doleritic in character

and shows spheroidal weathering well. The joints are filled with a fine impalpable pale blue steatitic clay. At the end of the wadi the Eocene beds are well seen, resting on one side of the valley on the serpentine and dipping only 5° to the south-west, while on the opposite side they are perched high up on the 'Omán limestones. This is shown in Fig. 2. About 70 feet of them is exposed consisting of a coarse pebbly grit at their base and passing up into yellow sandy limestones of a precisely similar character to those of Darzeit and Bandar Jissa. This wadi affords a very good example

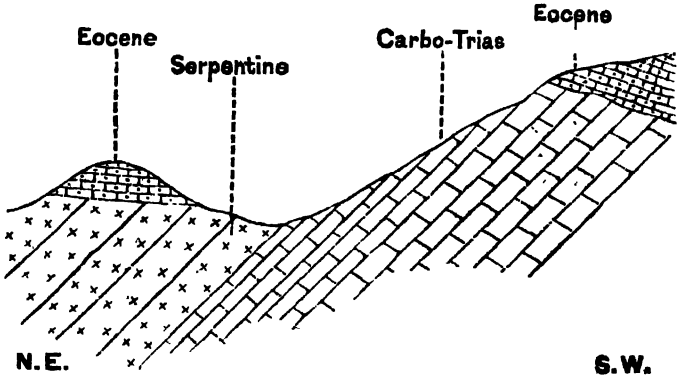

Fig. 2.—Sketch Section near Ruwi.

of the way in which limestones of very different types occur in juxtaposition throughout the 'Omán series. We see here the characteristic black limestone, which is met with from Masandam to Jebel Jaalan, associated with paler crystalline limestones, and also with the limestones in which crushing has induced such great fissility that it is possible to cleave them into flakes no thicker than a knife.

Between this wadi and the plain of the Saih Hatât 10 miles away is developed a great complex, consisting chiefly of limestones

of all these various types. Here and there occur outcrops of the Hatát beds with intrusions of diabasic sills. There is no doubt that the beds are greatly folded and contorted, and this fact joined to the absence of fossils rendered it impossible in the short time at my disposal to unravel the relations between the different beds.

It will perhaps be most convenient to start my descriptions from the single locality in which I found any traces of fossils; this was in the bed of the Wadi Adi, about three miles from Ruwi. All the beds are dipping about 35° N.E. In an intensely black fetid limestone are innumerable silicified remains of brachiopods belonging probably to the genera *Spirigerella* and *Athyris*. With these were Cyathophylloid corals.[1] Higher up than this bed the limestone contains *Orthoceras* and Encrinites and is of a red colour. Still higher are thin slaty beds, red and yellow in colour. Immediately above these is a pale blue limestone in which the best fossils were found. Unfortunately the limestone proved so hard and siliceous that it was generally impossible with the instruments which I had with me to extract them. The most abundant fossil was a species of *Productus* allied to *P. indicus*. I also recognized representatives of the genera *Spirigerella*, *Dielasma*, *Camarophoria*, *Athyris*, *Orthothetes*, and *Streptorhyncus*. In contact with this limestone was a yellowish slaty shale containing Bryozoa probably belonging to the genera *Aulopora*, *Fistulipora*, *Protoretopora*, and *Fenestella*, and a coral resembling *Michelinia*. The general appearance of these reminds me very much of some of the Permo-Carboniferous Zewan beds in Kashmir. These fossils leave us in no doubt as to the Permo-Carboniferous age of the beds which contain them, and they correspond perhaps to the middle Productus limestone of the Salt Range.[2] The fossiliferous bed is hardly more than four or five feet thick, and although there is no difficulty in tracing this bed in both directions

[1] Prof. Diener has identified these as a species of *Lonsdaleia*.

[2] Since writing the above I have seen the results of Prof. Diener's examination of a few of these fossils which I brought away with me. He has confirmed my attribution of the *Productus* to *P. indicus* and has referred another brachiopod to *Hemiptychina cf. sparsiplicata*.

along the strike, the fossils are confined to within a distance of a yard or two. They generally form the nucleus for concretions of iron oxide, and one can notice identifiable fossils shading off into mere shapeless siliceous iron-nodules. It appears that by some fortunate coincidence this small area escaped the crushing, which has for the most part destroyed all recognizable traces of fossils throughout the series. These limestones contain a considerable amount of quartz occurring sometimes in layers, sometimes in cavities. Below these fossiliferous beds flaky limestones occur, while the lowest beds that one can recognize are quartz schists and hornblende schists belonging probably to the Hatát series. These are intruded by diabase along the bedding planes. Proceeding south along the Wadi Adi nothing else but limestone with a high and generally westerly dip and showing evidences of considerable folding is encountered until we reach the entrance of the Saih Hatát. Here limestones, often partly crystalline, and sometimes very fissile, are interbedded with purple sandstones, which have evidently been very much crushed, and thin layers of slaty shale. Below are calc schists, passing into regular green hornblende schists belonging to the Hatát series. The plain of the Saih Hatát, which is about 20 miles long by 10 broad, shows no other rock series except this. The plain is dotted with low ridges, which do not run very far and hardly ever exceed 20 feet in height, while often they are no more than mere excrescences on the surface of the plain. These ridges are composed of greenish grey chlorite schists and brown or yellowish brown mica schists. Their strike is fairly uniform, the planes of foliation dipping some 20° to the west. Veins of quartz intersecting these schists at all angles to the planes of foliation, are very numerous. They vary in thickness from a few inches up to six feet. A breadth of two to three feet is very common. Purple and green quartzites are exposed in the Wadi Amdah on the southern side of the plain on the sides of Jebel Beidheh, and here also calc schists are interbedded with the more usual types occurring out in the plain. Overlying these are massive blue limestones, which evidently belong to the 'Omán series. Lieutenant-Colonel S. B. Miles (29), who crossed

the range of Jebel Beidheh by the Wadi Kahzeh and passed along its south-western side by the Wadi Tyin, refers to the occurrence of massive limestone, so that we may conclude that the whole of this range consists of the 'Omán series. It is also clear from the specimens of the black limestone collected in the mountains of Jebel Jaalan by Mr. C. S. D. Cole (3, p. 109) and referred to by H. J. Carter (9, p. 565) that the 'Omán series extends very much farther to the south-east. From what I know of the constancy of this formation and the prominence of the topographical features with which it is associated, it is extremely probable that the outcrop is continuous. Miles states that the range of Jebel Hallowi, which runs parallel to that of Jebel Beidheh but more to the south-west, and which is separated from it by the Wadi Tyin, consists of igneous rock like that at Muscat, so that it seems likely that we get as large a development of the serpentinous series as is the case in the Wadi Samáil. The whole of the Saih Hatát is bounded by limestones of the 'Omán series which overlie the crystalline schists.

Returning now to our fossiliferous outcrop in the Wadi Adi it is seen that going north towards Ruwi nothing but the unfossiliferous 'Omán limestones appear, dipping steeply north-north-east. Close to Ruwi the wadi opens out and divides into more than one branch. One of these goes north towards the village of Lutayi, while the other bending round to the east leaves Ruwi on the right hand, traverses the small plain mentioned above (page 89), and finds its way to the sea at Darzeit. The former of these two branches narrows considerably before reaching Lutayi. The hill on the east which is a continuation of the Nummulitic saddle, running south-west from Darzeit, shows an exposure of the Eocene pebble bed dipping 15° E.S.E., and here attaining a thickness of some 60 feet. In places it passes into a compact buff coloured sandstone. It here overlies purple and green schists of the Hatát series, a continuation of the outcrop further to the south-east near Ruwi. On the opposite side of this wadi the 'Omán limestones are dipping steeply to the north-west and give the appearance of underlying the schists which are also exposed on this

side. It would therefore seem that there is considerable unconformity between the two series. Between this point and Ruwi the pebble bed is seen resting on the fissile limestones of the 'Omán series, on the red jasperitized beds, and on grey flaky shaly limestones. These are here vertical. The sharp contortions and foldings of this series are to be well noticed in a hill lying about a hundred yards north of Ruwi and also at the end of a small wadi going up to the south-east from Ruwi. Here all the beds are dipping north-east and compact blue limestones containing red iron concretions, like the fossiliferous outcrop in the Wadi Adi, are underlain with every appearance of conformity by extremely fissile limestones, often very crystalline and in their lower part penetrated by sheets of quartz, which have been reduced by pressure to an almost flaky condition. I may here say that I have nowhere had any evidence that these different types of limestone are not members of a perfectly conformable sequence. I have seen them in many different localities and always in juxtaposition, as is the case here, and their different appearance must, I think, be ascribed wholly to the different ways in which their petrological constitution has caused them to be affected by exactly the same pressure. At the base of this section are lustrous silvery grey mica schists. These schists are seen nearer Ruwi intruded by diabase of precisely the same character as that of the Wadi Adi.

I now come to my journey inland to the south-east of Muscat. This lay through the village of Lutayi, which I have already mentioned. For some while before reaching it, the hills of the Nummulitic grit are very noticeable on my right, while on my left the 'Omán limestones almost join the track, lying on the flanks of the lofty range, which is a continuation of Jebel Tyin. From Lutayi the road lies exclusively amid low flat-topped hills and ledges of yellow or buff coloured Nummulitic limestone, from 10 to 30 feet in height with a low dip, rolling in various directions. *Diplopora* sp. *cf. flexuosissima* D'Arch. was found here. Inland tall hills of drift sand, resting against the limestone range, are very noticeable; they extend for many miles and are especially lofty near the village of Bosher, to

the west of which I saw no more of them. These sandhills may be of the same age as the false bedded sands which I have noticed as occurring near Baital Falaj (page 89), but are probably much more recent. The pebble bed is not always exposed, but at the village of Umsad it is 20 feet or more thick and is of a strikingly black colour on account of the black limestone of which most of its pebbles consist. It is overlain by alternating layers of fine sandstone and coarse grit with a dip of 20° N.N.E. In the lowest bed of all the pebbles are of a great size, and the strata are deeply coloured by iron, derived doubtless from the lateritic bed, found at the base of the series at Darzeit and elsewhere. At Liqfa the pebble bed is 40 feet thick and is overlain on the sides of the wadi by a recent or sub-recent pebble bed 6 feet thick. Near Liqfa starts a large outcrop of igneous rock. It is somewhat varied from the igneous rock of Muscat, but its character approximates sufficiently to the latter to make it clear that the two belong to the same series of eruptions. Various types of rock are seen, which all shade into one another from place to place. They are all intensely basic, but generally exhibit less alteration than the Muscat rock. Amongst them are gabbros with large crystals of diallage and olivine, passing into dolerites, many of which are exceedingly fine grained. In other places a dioritic rock which has assumed a somewhat schistose structure and may be termed an epidiorite is fairly frequent. This often passes into a diabasic rock, which is not unlike that seen in the Wadi Adi and near Ruwi. Several of these rocks contain large amounts of iron, both as magnetite and hæmatite. It is quite clear, whatever may be our opinion about the Muscat rock, that all of this is plutonic in origin and represents a large boss or sill with which surface flows may have been connected. I can form no idea of the thickness of the beds in this outcrop, though it might easily have been as much as 1,000 feet.

Some 4 miles from Liqfa the Nummulitic pebble bed is again encountered having a dip of 30° W. We have now reached a range of hills running north-north-west and south-south-east which is entirely Eocene. The lateritic formation representing a continental period

which may have been during Cretaceous times is very apparent here. Not only is there the ironstone as seen at Darzeit, but a bed of pisolitic laterite is also present, which Mr. E. Vredenburg tells me is very similar to a deposit which is very widely spread in Baluchistan and Sind.

The Nummulitic formation continues almost as far as Mizra, a village nestling at the very foot of the lofty limestone chain. The dip is at first 30° W.N.W., but on nearing the edge of the outcrop it is seen to be reversed and the beds now dip east-south-east. The dark greenish serpentine rock of Muscat composes many of the hills near Mizra. An actual junction with the flaky limestones of the 'Omán series is seen in the village of Mizra itself.

The dip in both cases is vertical. The serpentine passes into the same schistose hornblendic rock, which occupied such a large area near Liqfa. At the village of Sunab which is further to the east, but also at the foot of the same high range, I observed a sill of Muscat serpentine some 10 feet broad intruded into compact blue or reddish limestone. The latter had been rendered quite crystalline near its junction with the intrusion. From Mizra the road goes slightly west of north keeping to the igneous rocks, but not far from the margin of the Nummulitics. A conspicuous feature on the left hand is a long, flat-topped hill some 500 feet above the plain, consisting of the same buff coloured limestone, whose appearance is in such striking contrast to that of the other formations of 'Omán. These limestones are underlaid by mottled clays, passing down into a red pebble bed which is here 80 to 100 feet thick.

The road now goes to the south, and the bed of the wadi becomes rather steep. The Nummulitic beds are left behind, and we pass on to the older formations. Serpentine and other igneous rocks of the same series are seen in contact with the limestone of the 'Omán series. These latter are very noticeably crystalline. Their dip is 35° N.E. The igneous sills are here of no great thickness, but it is not usual to find places where they can actually be seen interbedded with the limestones. They are clearly seen to underlie and also to

overlie the limestones; but the Nummulitics, which were deposited on the very greatly eroded surface of both of them, appears generally to have covered the upper junction of the sill with the 'Omán limestone. Still there are places where the intrusive character of the serpentinous series is settled beyond a doubt.

A very little further to the south the Hatát series is found underlying the serpentinous rocks, which are clearly intrusive into it. The Hatát beds present the same appearance as they do when seen elsewhere. There is a great development of quartzites, of brown, green and purple tints. Quartz veins are numerous, and their sheet-like character produced by the severe crushing is even more marked here than I have observed in other places. The outcrop of the Hatát series is not wide and ceases before reaching the village of Nafa'a. We are now well within the wide plain occupied by the Wadi Samáil and its tributaries and which has a general elevation of 2,000 feet above the sea. The whole of it, that is to say, an area some 12 miles in breadth, is almost entirely filled with rocks differing in no respect from the Muscat serpentine. This is met with in hills which though sometimes attaining an elevation of 500 feet above the general plain level, are yet very inferior in height to the two lofty ranges of the 'Omán series between which they lie, and which are known as Jebel Nakhl and Jebel Tyin. The latter is probably an offshoot of the mountain range of Jebel Akhthar. The dips are generally indistinct, but on the whole the several ridges of serpentine seem to be striking north-east to south-west. The Wadi Samáil, marked out by its luxuriant date gardens, occupies a strike valley, and keeps nearer the north-western side of the open plain, which, as I have mentioned above, is coterminous with the outcrop of igneous rocks. I was able in more than one place to reach the north-western boundary and to see the junction of the serpentine with the 'Omán series. Further than this it was impossible for me to go on account of the hostility of the Arabs. My clearest view of these beds was obtained in the Hobh plain, but this was only effected by a very rapid and stealthy visit on the same day as I arrived in the village of Samáil, and before the

Bedouin tribes of Hobh knew that I was in the neighbourhood, and was attended with a certain amount of risk, if my presence had been discovered. The character of the 'Omán series is precisely similar to that which has been noticed in other places. The dark coloured limestones contain unidentifiable corals and other fossils. The dip is fairly regular to the south-east and is high.

With the limestones are numerous beds of red chert, and intruded masses of serpentinous rock. I saw one bed of quartzitic sandstone.

In the bed of the wadi is an abundance of hard conglomerate containing pebbles of limestone and of serpentine. This overlies the serpentine, and, rising to some 8 feet above the general level of the water in the wadi, is being much undermined and eroded by the floods of to-day. I can form no idea as to its age, though it is probably as old as Pleistocene.

I have now to deal with the extreme westerly portion of 'Omán, including the peninsula of Ruus El Jibál, of which the eastern side is under the jurisdiction of the Sultan of Muscat, while the western side is governed by the so-called Trucial chiefs and is known as Trucial 'Omán.

At Khor Fakkán we know from Dr. Carter's record of the existence of a large outcrop of serpentinous igneous rock similar to that at Muscat, and a couple of miles to the south-south-east of Dibah I found a further large outcrop of serpentine with magnesite veins. The strike seemed to be east-north-east—west-south-west, the dip being some 35° N.N.W., and as far as the eye could see, the same type of rock extended to the south-south-east.

Dibah itself lies in a broad flat plain some 3½ miles broad and stretching inland some 6 miles. North of this plain rise up lofty hills of the 'Omán series, of which, as far as I could judge, the massive limestones were exposed right along the coast up to the Quoins. This peninsula, especially towards the end, is remarkable for the deep indentations which the sea makes in the land. These fiords are very deep and narrow and are plainly buried river valleys. In Elphinstone inlet on the western side of the peninsula, once the site of a

telegraph station, Dr. W. T. Blanford found fossils in the limestone—a *Myophoria* with distinctly Triassic affinities and an *Exogyra* of a type not hitherto found in beds earlier than Jurassic. The limestones differ in no way from that of Carboniferous age found elsewhere in 'Omán, hence it may well be that portions of the series met with in Jebel Akhthar are also Triassic. I marched right across the peninsula from Dibah to Rás Al Khaimah, and the following is a brief resumé of what I observed on the journey. Some 5 miles from Dibah a modern wadi begins, cut out of an ancient alluvium, of which the banks on either side attain a height of 50 feet. The hills on the left consisted of serpentine. This gives place to the 'Omán series, in the pale blue or yellow limestones of which I saw several unidentifiable fossil remains. The bluish grey chert forms thin beds in the massive limestone.

Some 10 miles from Dibah the serpentine again crops out in the wadi up which my course lay, and after a considerable distance gives place to the 'Omán series again. There was no type of bed which I found in this series near Muscat which was not represented here. The dip here is to the west-south-west at angles of from 20° to 40°. The watershed is crossed imperceptibly.

Some 10 miles from the coast at Rás Al Khaimah the 'Omán series is overlain with perfect unconformability by a yellow limestone resembling very closely the Nummulitic rocks seen near Muscat. I found no fossils in it and can only provisionally assume that it is tertiary in age. In places I found at its base a conglomerate containing pebbles of the various members of the 'Omán series together with igneous rocks. The beds roll about, but the dip is not very great. The road keeps on the level at the base of the hills of the 'Omán series. Away to the south-west stretches a plain broken only by a long low line of red sandhills more than 100 feet high and 6 to 8 miles from the sea. These sandhills cover a wide belt, and numerous recent shells are found in amongst them. Their red colour is due to red chert grains, but where the rock is situated, that has by its erosion produced all this material, I am unaware.

Qath was the last village where I was in touch with the 'Omân series. This is some 5 miles in a straight line inland from the red sandhills just mentioned. A hot spring at a temperature of about 120° F. juts out of a narrow cleft in the well-bedded 'Omân limestones. The limestones are here dipping 65° W.N.W., and the hot water channel runs apparently across their strike. There are two or three of these hot springs at various places at the foot of these hills. The limestone at Qath is full of iron nodules, the remains of organisms. In places there are evidently some branching corals resembling *Lithostrotion* and a species of *Spiriferina* which I failed to extract. A flat marshy plain lies between the red sandhills and Rás Al Khaimah. Further south there are sandhills rising up quite near the sea, but nothing else to be seen for miles inland.

CHAPTER IV.

THE COAST BETWEEN BANDAR ABBÁS AND LINGAH.

The country which lies to the north of this line of coast remains now in the most unsatisfactory state of any portion of Persia as regards our geological knowledge of it. For a distance of more than 150 miles inland we know nothing, and our ignorance embraces the country for considerable distances both to the west and the east of the area which lies immediately north of a line joining Bandar Abbás to Lingah, and the possibility of guessing, with some measure of assurance that our guess is founded on probability, is not open to us here as in many parts of Persia, because my observations on the coast have shown that the disturbance in this area has been great enough to expose rocks different in age to what one would expect by following the strike of the hill ranges north-west into the known areas. The

bending round of the ranges to the south as shown in the coast-line between Bandar Abbás and Gwadár also points to more complicated conditions, both of deposition and folding, than has been noticed north of Bushehr and in the Bakhtiyári mountains. All I can do therefore is to describe the formations which I met on the coast with the hope that at no distant time it may be found possible to unravel the geological structure of the interior.

And first it will be more convenient to consider the country round Khamir where all the formations met with on this coast are represented in a small area.

They are the following :—

'Omán series and basic igneous rocks connected with it.
Hippuritic limestone.
Hormuz series.
Nummulitic limestone.
Fars series.

The geological sketch map (Plate XIV) will enable my descriptions to be followed more easily. The great range of Dozgan, which joining the sea at Khamir runs in a west-north-west direction, consists in the main of rocks of the Nummulitic series. These are sandstones, with intercalated bands of thinly bedded marl or argillaceous limestone containing flints. At the base these limestone bands are still more flaky or rubbly and contain *Nummulites intermedius*. This gives us an Oligocene (stampian) age for these Nummulitic beds (page 22). The dip of these beds is rather steep to the north-west in the tall cliffs. The Nummulitic formation, however, has been folded sharply over, and the beds as seen at Khamir form an anticline whose crest has been denuded down exposing inliers of the older rocks. These older rocks are either Hormuz or hippuritic limestone. Fig. 3 exhibits a diagrammatic section of the beds occurring immediately north of Khamir.

About 3½ miles west-north-west of the village of Khamir is a hill some 200 feet high, of limestones with hippurites dipping 75° W.N.W. Possibly a thickness of some 200 feet of limestone is here exposed. Overlying these is a great thickness of grey calcareous shales. There is no appearance of unconformability between these shales and the hippuritic limestone, and I have considered them as belonging to the Cretaceous. I here found *Exogyra matheroni* D'Orb. and *Radiolites* sp. so that the limestone is probably of senonian age. Further outcrops of hippuritic limestone are found half a mile or so further to the north-east at the base of the Nummulitic cliffs.

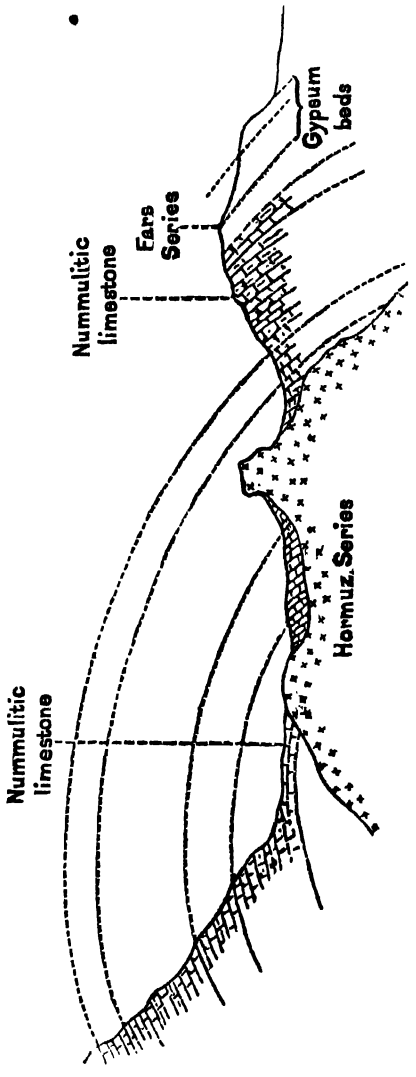

Fig. 3.—Diagrammatic Section at Khamir.

Overlying both the hippuritic limestone and the shales with every appearance of unconformity are rocks of the Hormuz series. As usual the red ash bed is the most conspicuous feature of the formation. Here and there it can be seen cropping out in the various low hills between Khamir and the main range,

where the overlying Nummulitic rocks have been denuded away. A portion of this red tuff penetrates the hippuritic limestone as a very narrow band in continuation of a very much more extensive outcrop of the same rock occurring a few yards away interbedded with sedimentaries and salt belonging to the Hormuz series.

This fixes the age of the Hormuz beds as later than senonian and earlier than stampian. It seems likely that their formation and folding took place before the deposition of any of the Nummulitic rocks in this part of Persia, *i.e.*, in the Lower Eocene. This would make these igneous phenomena as nearly as possible contemporaneous with the Deccan trap flows of India, to which, however, they present no lithological resemblance (page 16).

Overlying the red tuff and sometimes in contact with it and sometimes with hippuritic limestone is a rhyolite which to a great extent seems to have been completely decomposed. Near the junction with the hippuritic limestone fragments of limestones are very frequently found enclosed in this. Its entire substance is completely permeated with sulphur. The sulphur has penetrated the hippuritic limestone in places and has rendered it quite friable. Gypsum is also found in great abundance through this mass.

At Bostanah, 16 miles west of Lingah, there is another occurrence of sulphur in a rotten rhyolite of precisely similar character. It seems most likely that the formation of the sulphur, though probably not contemporaneous with the rhyolite, is not far removed in age from it and belongs to the same volcanic period. For there is certainly no trace of sulphur to be found in any of the later rocks, whether Oligocene or Miocene, in the neighbourhood. The natural inference to draw is that the sulphurous activity had ceased : apparently oxidation of the sulphur has given rise to sulphates which, acting on the older limestone, has led to the formation of gypsum.

An exceedingly common rock in this area associated with the Hormuz rock is a coal black, very crystalline limestone, emitting a fetid odour when freshly broken.

Only the basal gypsum beds of the Fars series are represented

at Khamir. They occur in the hills immediately north of Khamir bordering the plain, stretching about one mile to the west and a considerable distance to the eastward. (See Fig. 3.)

They are dipping at angles of from 35° to 70° to the south-east and rest on rubbly limestones containing *Nummulites intermedius*, which are therefore Oligocene or of Lower Nari age.

The following section is exposed:—

Gypsum, 150 feet, interbedded with buff coloured clay, veined with gypsum.

Sandy limestones.

Sandstones, generally buff coloured, soft and shelly, with interbedded pebble beds.

Harder limestones.

Some of these beds are very shelly, but the only recognizable fossils found were *Balanus* sp.

These beds are found along the coast to Bandar Abbás where all the low hills behind the town consist of Fars marls. At Kuh Namak, some 20 miles to the east of Khamir, there is a further extensive outcrop of the salt series, but to what extent Hippuritic or Nummulitic rocks are here represented I am unaware.

From the consistency with which all the rivers for 100 miles inland are reported as being salt I should think it likely that the rocks of the Hormuz series, even if they do not actually crop out between the Nummulitic or Cretaceous ranges, are beneath the surface and point to an extension of the Hormuz area thus far.

Here and there lying in the midst of the red tuff, and also found in association with masses of salt, are blocks of an altered plutonic rock, originally probably a diorite; there is abundant chlorite in it which imparts a vivid green colour to the whole rock and large amounts of epidote. This same rock is found in similar situations at Bostanah and Hamairán. These fragments of chloritic diorite, obviously of the nature of ejecta, may be derived from a deep seated rock of the age of the Muscat serpentine series. Its character is quite different from that of any bed of the Hormuz series and is more akin to some of the

'Omán rocks. This rock, though very much altered, suggests a resemblance to the Henjám occurrence (page 133). It seems probable therefore that its age dates to a period prior to the Hormuz rocks. Moreover, both at Bostanah and at Hamairan, also at Al Buża on the sea-shore between Hamairan and Lingah, extensive outcrops of the same chloritic diorite occur *in situ*, associated both with plutonic rocks, which bear a still closer resemblance to the 'Omán igneous series, and also with limestones, which are so nearly like the 'Omán series and so unlike any of the Hormuz sedimentaries as to justify me in referring them thereto. Further, rhyolites, red ash beds, and red sandstones which undoubtedly belong to the Hormuz series are found near these, but with quite an unconformable strike to the presumed 'Omán rocks. (See page 111.)

Some 4 miles west-south-west of Khamir village a small hill rises out of the plain. At its base is the same rhyolite of the Khamir sulphur mines. Overlying it are brownish, thin flaggy limestones, and over these are pink and white micaceous sandstones. All these beds dip about 30° N.W. Micaceous hæmatite associated with gypsum occurs in the joints or forming veins in the sandstones. Loose blocks of the green chloritic diorite are seen lying near by. Another small hill, a quarter of a mile away from the last, is made of the rhyolite.

With the exception of the two isolated hills, which have just been described, there is nothing for a distance of 18 miles from Khamir but sand or alluvial deposits. Between the road and Clarence Strait lies a broad stretch of swampy ground which grows some abundance of low mangrove shrubs.

Near the village of Turadun, however, the monotonous level is broken by a line of hills striking approximately north-west and south-east and dying away towards the sea. These belong to the Fars series and present the typical coast facies, consisting of pale blue or grey clays, sometimes sandy, veined with gypsum, and also saliferous. Interbedded are shelly bands which are often conglomeratic. These beds are dipping 20° N.E. These hills continue as a series of small

scarps to the foot of the big range of about 3,000 feet elevation, which at high water is washed by the sea. It is necessary therefore for travellers to make their passage round this hill correspond with the time of low tide. These all appear to be of the same nature as the other, and are beyond a doubt strictly conformable to it. The dip gradually diminishes from 20° to 10° in a south-easterly to easterly direction, and within the above-mentioned range this further diminishes to 5°.

This range is cut through by several exceedingly deep ravines, having in many cases precipitous walls 200 feet or more in height. At the time of my visit, that is, in April, these river courses were either quite dry or had only a small trickle of water in places, but in the brief rainy season, during December, the streams doubtless assume somewhat larger proportions. Here and there oleanders, polygonums, and other flowering shrubs, growing in the sand or rock, gave it quite a gay appearance. I went up one of these ravines which afforded a by no means uncomfortable pavement, as for long distances the track lay on the same bed of rock worn quite smooth by water action. It led right up into the heart of the range where a complex of thickly massed hills offered a formidable barrier to our further progress.

All the rocks met with in the big range may clearly be classed with the two lower divisions of the Fars series. As I did not, however, see quite close the rocks through which they pass up into the beds containing the typical fossils of the *Pecten vasseli* beds, I am unable to trace the lithological changes. The following in descending order is a section of the beds encountered in this range:—

Pale grey clays.

Shelly limestones with sandy clay and pebbles.

Hard argillaceous limestones, variegated red, white and grey.

Gypsum band, 4 feet.

White or mottled clays.

Sandy limestone.

Gypsum band, 3 feet.
Mottled indurated clay.
White, slightly siliceous limestone.
Gypsum band, 4 feet.
Mottled calcareous clay.
Gypsum band, 2 feet.
White shelly limestone with *Ostrea* sp. and *Pecten* sp.
Clay with lumps of gypsum.
Nodular calcareous clay.
Gypsum band, 2 feet.
Shelly limestone.
Pure hard limestone.
Red indurated clay.
Red plastic clay.
Argillaceous limestone with *Ostrea verleti*, *Pecten substriatus*, and *Cidaris* spines.
Grey limestone with *Moira* sp. *aff. antiqua* Dunc. and *Agassizia* sp. *aff. lovisatoi* Cott.

From here on the exact sequence of the beds was difficult to follow in the confused mass of hills which lay before us. The dip, however, remained slight, 10° S.E., and in a short time descending steeply to the sea we traversed a great thickness of rock-gypsum, evidently the same beds seen at Khamir in contact with the Oligocene limestone. I did not reach their base here, but the thickness traversed cannot have been less than 300 feet. (*Cf.* Fig. 4.) The total thickness of the entire Fars series exposed in this section from Turadun to Birkah Siflah cannot be less than 8,000 feet. The gypsum beds are exposed on the sea-shore dipping 10° E S.E. Going along the sea-shore to the east I found lower beds exposed, limestones having a frosted appearance due to contained gypsum and salt. These beds bend sharply over on themselves as shown in the sketch (Fig. 4), and the dip is from 60° to 70° S.E. or S.S.E. These beds may be a representative of the Urmi series. Before long considerable beds of rock-

gypsum are exposed on the sea-shore dipping at 75° and running for some distance parallel to the shore-line, which here trends in an almost southerly direction. This gypsum is of excellent quality and can be mined and laden on to boats with great ease. The gypsum beds bend about and are contorted considerably within a short distance. Thus we see that this locality forms no exception to the rest of Persia in the extensive folding which the basal gypsum beds

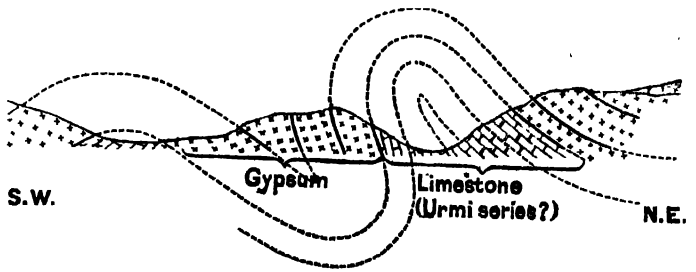

Fig. 4.—Sketch Section of Fars beds near Birkah Siflah.

of this series seem almost universally to have undergone. Here, as in so many other places, the beds are squeezed into a sharply ridged anticline having on either side of it beds with only a very slight dip.

After leaving Birkah Siflah my route lay through low hills in which the higher beds of the Fars series were exposed rolling about with low dips, and presenting a very similar appearance to that which is the case in Kishm island. The road followed a rather zig-zag course in order to avoid the hills, sometimes approaching the sea and sometimes receding from it.

About 2 miles before reaching the village of Hamairan volcanic rocks of the Hormuz series crop out associated with sedimentaries.

These continue along the coast up to Hamairan and extend some 4 miles inland, being overlain by gently dipping beds of the Fars series. At Hamairan I went up into the hills and made some observations on the Hormuz rocks. Besides the red tuffs and salt beds is a greater development of sedimentaries than I have observed elsewhere. The most conspicuous member of this sedimentary series is a pink micaceous sandstone some 60 feet or more thick. There are also brownish, rather flaky limestones of similar character to those which I have mentioned as occurring in some isolated hills near Khamir (page 106). A considerable amount of the black fetid limestone of Khamir also occurs here, in places quite crystalline and in others shading off into non-crystalline rock. Veins of quartz occur in this limestone.

All these beds are dipping at angles of 40° or more, generally to the south-west, but are manifestly folded. Rhyolites are interbedded. Fragments of the same plutonic rock mentioned on page 105 also occur here. After leaving Hamairan some 6 miles of perfectly flat country intervene until a scarp made up of the white chalky limestones of the Fars series breaks the monotony. These are succeeded by lower beds dipping to the north-east, at first about 20° but gradually increasing to vertical.

The Fars beds are displayed in a series of irregularly massed hills with small outcrops of the red Hormuz volcanic tuffs cropping out here and there amid them. At Al Buza the outcrop of the Hormuz series becomes continuous, and I think that the hills for some 20 or 30 miles to the north-west consist of the same formation, although on the coast the outcrop is not broad, and after less than a quarter of a mile they give place to the Fars rocks.

The beds exposed on the sea-shore at Al Buza are interesting as affording good grounds for believing that older beds of the 'Omán or serpentinous series immediately underlie the Hormuz formation. Flaky limestones dipping 75° N.E. are interbedded with the green chloritic diorite found as ejecta at Khamir, Hamairan, and Bostanah, while a hornblendic schistose rock also is found bearing a considerable

resemblance to some types of the serpentinous series in 'Omán. Furthermore, in juxtaposition to this is a compact blue limestone, in places shading into brown, containing several red iron concretions whose resemblance to some of the fossiliferous limestones of the 'Omán series is quite striking. These are overlain with unconformable strike by pink micaceous sandstones dipping 20° E., passing into the red tuffs and the rhyolite; red conglomerates containing rounded limestone pebbles are found in association with the more ordinary ashes without pebbles. An occurrence of very much contorted flaky limestones reminds one strikingly of much that occurs in the Carbo-Trias of 'Omán.

Shelly grits and pebble beds of the Fars series dipping 30° into the sea overlie the purple conglomerates mentioned above with perfect unconformability. For about 4 miles before reaching the town of Lingah the road never rises above the dead level, and few or no exposures of the Fars series are visible.

From Lingah I paid a visit to the sulphur mines of Bostanah situated on the coast about 20 miles west of Lingah. The pile of Jebel Bostanah, near the village of that name, comprehends a collection of hills attaining an elevation of 1,800 feet and consisting mainly of rocks of the Hormuz series. At the base of the hills the same pebbly shelly bed of the Fars series noticed west of Lingah is seen dipping 75° S.; with this also are clays and chalky limestones having a lesser dip to the south. All lie on the upturned edges of the Hormuz series, which consists of the pink micaceous sandstone and other types found elsewhere. Micaceous hæmatite is found in joints and veins throughout all these older rocks. A red jasperitized shale also occurs in some quantity. On the top of a hill of mingled trachyte and gypsiferous earth occur huge blocks of the chloritic diorite, of basic igneous rocks, and of limestone resembling much those found throughout the 'Omán series. It seems evident that these have been brought up by volcanic forces into their present position.

CHAPTER V.

THE BAHRAIN ISLANDS.

During my visit to the Persian Gulf, I was able to make a somewhat more thorough geological examination of the Bahrain group of islands than was possible in many other cases. They possess many features of interest quite peculiar to themselves. These are the only islands in the Persian Gulf on whose geology we have hitherto had no information. This is the more remarkable, as their structure seems not only to be essentially different from that of all the others, but to be of a type which has not been observed either on the Persian coasts or on those of 'Omán or Masandam.

The omission is perhaps due to the fact of all rock not of recent coral formation being some considerable distance removed from the shore, and for this reason somewhat difficult of access by Captain Constable to whose specimens collected in the Gulf in 1840 and described by Dr. Carter we owe most of our previous information on the Persian Gulf islands.

The Bahrain islands receive their name from the largest of them,—Bahrain,—which is some 29 miles long by 10 broad. The others are very much smaller, their names being Muharraq, Sitra, Umm Nahsan, Jiddi, Raka, and Nabbi Salih. They lie in lat. 26° N., long. 51° E., within the arm of the Persian Gulf, bounded on the west by Al Katif and Hasa and on the east by the peninsula of Qatar.

The islands have been described generally by Bent (27) and Zwemer (34), and Captain Constable furnished the materials for a brief note by Carter (12, 361-363).

Bahrain itself will have our first attention. Within the island, as can be understood by reference to the accompanying map (Plate XII), is a large, approximately oval area some 12 miles long by 4 broad, clearly delimited by an almost continuous line of cliffs broken only at one point to the western side near the cluster of huts known as Sakhir, by a ravine leading out in the direction of the sea. These cliffs are at a distance varying from 1½ to 5 miles from the sea. Crowning them at

their highest part, at the north-eastern angle of the depression, is the hill fort of Rifa'a Ash Sharki, often known merely as Rifa'a.

From the summit of the cliffs the ground, after remaining flat for some distance and so forming a kind of plateau, slopes down, for the most part imperceptibly, to a sea-level plain, which stretches inland for varying distances from the sea. The plateau is at a general height of from 150 to 200 feet above the sea, and the scarped cliffs are from 80 to 100 feet high. The plain lying at their foot is sandy with a thin crust of recent marine sediments in places, and here and there some low hills rising above the general level; but on approaching the centre of the island, the sandy surface of the plain is replaced by limestone which is often almost flat with the plain, and seldom rises very far above it. This limestone formation culminates in a cluster of some seven peaks, extending over an area of nearly a square mile and 440 feet above sea level, known as Jebel Dukhán.

The circle of cliffs is much indented and narrow-necked promontories run out into the plain. Occasionally these narrow necks have been worn away, and so isolated hills have been formed, detached from the main line of cliff.

The rocks met with may be considered in three divisions:—

1. Limestones and marls of eocene age.
2. Miliolitic formation, probably pleistocene.
3. Sub-recent sands, coral limestones, and littoral conglomerates.

1. Eocene.

The core of Bahrain consists of rocks of this age. Fossils permitting of identification have not been found throughout the series, but there seems no just ground for separating the limestones of Jebel Dukhán and the central portion of the island from those of the circle of cliffs and the adjoining plateau.

Two points strike one as being characteristic of all these rocks as a whole:—

1. The extraordinary abundance of siliceous matter either in the form of layers of flint or cherty concretions or quartz geodes.

2. The marked dissemination of gypsum and salt throughout the series, not in any great quantities in any one place, but sufficient to cause a copious inflorescence either on the weathered surfaces of the rock or in the soil arising from their disintegration.

The series seems to consist of beds of hard compact limestone, often with concretionary flints, alternating with soft saliferous marls, which weather easily. These succeeding alternations of hard and soft beds give rise to a well-pronounced scarped structure in several places throughout the island.

It may here be remarked that throughout the series the dip is very slight, in fact often inappreciable and generally no more than 2° or 3°. South of Jebel Dukhán the dips are greater than they are elsewhere, and near Ain El Qar they are as much as 10°.

The various beds are disposed in a low anticlinal dome of which Jebel Dukhán forms the summit, and the circular cliffs and the adjacent plateau the margin. For this reason, it will be often hard to detect any dip in these cliffs as it will generally be inwards from the point of observation.

The accompanying diagrammatic section (Fig. 5) indicates the arrangement of the Eocene beds of the island. A thickness of some 500 feet is exposed, but neither the top nor the bottom of the series is seen. The oval of cliffs displays sections, which are almost identical in every place where I have observed them. That at Rifa'a may be taken as representative of the whole.

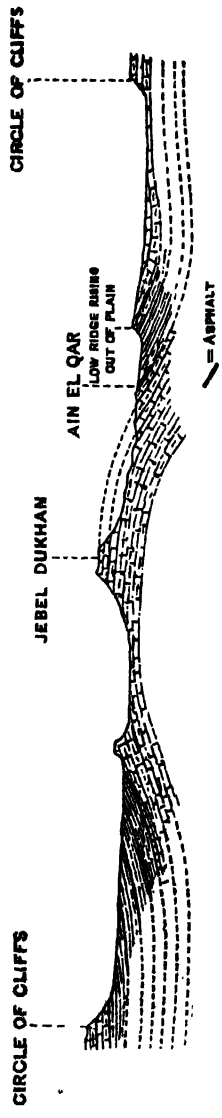

Fig. 5.—Diagrammatic Section from north to south through Bahrain I.

1. Hard pale coloured limestone containing numerous flints.	12 feet.
2. Hard pale coloured limestone without flints, sometimes containing a few foraminifera and echinoids.	9
3. White limestone containing foraminifera in plenty, weathering with a peculiar frosted appearance.	18
4. A yellowish layer with thin bands of biscuit shale, sometimes sandy, abounding in shells, especially *Ostrea elegans* var. *exogyroides* and shark's teeth, no foraminifera.	6 inches to 2 feet.
5. A soft chalk-like limestone of a dazzling whiteness, in parts clayey, in parts with calcareous nodules, containing nodules of ironstone. There are a few darker sandy layers intercalated and one 6-inch band of smooth unctuous shale.	40 feet.
	81

In a hill, 2 miles south-west of the bitumen deposit, which rises 120 feet above the plain, no less than 80 feet of this white chalk-like limestone (No. 5) are exposed, the foraminiferal beds overlying it.

The flints seem to be mostly confined to No. 1 bed, but I have met them also in the foraminiferal limestone just over the chalk beds, and I have found layers of flints in a nodular bed beneath the foraminiferal limestone. The flint bed No. 1 seems, however, to be constant, and the whole of the plateau described above, right down to the junction with the littoral flat, is more or less characterized by the presence of fragments of the hard limestone and flints mingled. The plateau is in fact a barren stony desert, where the only living things that meet one's eye are here and there a small plant of *Lycium arabicum* and a few lizards identified by Dr. N. Annandale as *Eremias brevirostris*.

The ancient inhabitants of Bahrain island in times long prior to history, possibly Phœnicians or possibly ancestors of the second Egyptian

race, have utilized the flints and limestone to build cairns probably of a memorial nature to their dead. These are spread over the Rifa'a plateau by the thousand, varying from 3 up to 10 feet in height and form one of the most remarkable features of the island. At Ali, 6 miles south-west of Manáma, the memorial mounds are on a more magnificent scale, rising to a height of some 30 or 40 feet, and excavations have proved that these are of the nature of sepulchres, as they contain chambers in their interior constructed of huge monoliths of limestone, which must have involved enormous labour to get into their present position.

It is rare to find any of this rock *in situ* when once on the plateau itself. But there are one or two old river channels some 12 or 15 feet deep where sections of the flint bed are shown. In one of these about 6 miles west of Rifa'a Ar Jibliá I found numerous specimens of *Schizaster mokattamensis* preserved in flint. I shall have occasion to refer to this old river channel later on when dealing with the Post-Eocene deposits.

After descending the cliffs at Rifa'a, the following exposures came under my notice in the course of a journey. Across the plain to Jebel Dukhán, about 1½ miles away from the cliffs a soft sandy marl is met with in the side of a narrow river channel, which contains numerous quartz geodes. These weather out and form a layer over the underlying rock. They are found in extraordinary abundance for most of the way between Rifa'a and Jebel Dukhán as round bodies attaining the size of a man's head with a surrounding wall of chalcedonic quartz, and within more or less perfectly formed quartz crystals. I saw no instance of the white chalky limestone passing down into the bed, but in some places I observed that the lower beds of the former rock was full of quartz crystals and concretions. These quartz geodes were found *in situ* in several low hills between this point and Jebel Dukhán, nor were they confined to the sandy marls, but existed also in limestones, often nodular and of pink or variegated colours. Moreover, limestones with flint bands seem to be interbedded, though on account of their superior hardness these

invariably form the tops of the hills. It is probable that these numerous quartz geodes are of later date than the beds in which they are found, and that their formation is due to the percolation of hot siliceous waters, by which the lime and more soluble materials have been taken away in solution while the silica has been precipitated in their stead. About 5 miles from Rifa'a an area is traversed where the whole surface is covered by continuously outcropping hard pale brown limestone. One of the most striking features of these rocks are that they are carved throughout by shallow grooves, which may be the result of sand polishing by wind action. In many places it is also observed that these rocks form a series of wedges, all facing one way with their thin ends to the north. I would suggest an explanation for this appearance in the fact that the prevailing winds are from the north-west and blow with extraordinary force and regularity during six months in the year; hence the surfaces of rock exposed to the sand blast will be worn away, while those behind might be protected.

In a section observed in a hill some 50 feet high and about one mile from Jebel Dukhán, this brown limestone is overlain by a soft white marl containing quartz geodes. This in its turn is overlain by some more brown limestone which contains crystalline quartz and also large concretions of a calcareous chert which weathers red on the outside. This peculiar form of chert is met with in Jebel Dukhán and here and there between Jebel Dukhán and the bitumen deposit. In the brown limestone on Jebel Dukhán I found some poorly preserved nummulites and a few unidentifiable corals and gastropods.

As the rocks occurring between these different outcrops are completely concealed by recent accumulations, it is impossible to state with certainty the way the different beds succeed one another, or even to say whether the lithological differences are due to variations in the same bed or to successive alternations of very similar deposits.

All that one can say with certainty is that between the white chalky limestone and the hard brownish limestone, which surrounds Jebel Dukhán, are beds of marly or nodular limestone, with numerous

quartz geodes, alternating with flint beds or cherty limestones. These quartz geodes form a conspicuous feature on the surface of the plain on every side of the brownish limestone outcrop which is the lowest rock of the series seen in Bahrain.

So far we have been considering only the Eocene rocks lying within the great depression. We have seen that the slope down to sea level from the cliffs is generally a gradual one. Between Rifa'a and Manáma, however, for some distance scarped cliffs, some 30 or 40 feet high, occur. The appearance of these is very similar to the Rifa'a cliffs, and here, too, long flat-topped hills have been separated from the main mass. A dip of 4° S. was here noticed, and there seems some ground for inferring that a synclinal structure has now replaced the anticline of the centre of the islands.

The rocks here exposed are the white frosted limestone containing nummulites and the opercula of one of the Turbinidæ in great numbers. In places at the base the rock is a white marl and contains red nodules of ironstone. This seems to be a portion of the chalky marl found at the base of the cliffs in the centre of the island. There is, however, no trace of the oyster bed. One must conclude, therefore, that the beds exposed are at a lower horizon than this. In the plain are traces of a flint-bearing bed exposed here and there.

North of these cliffs recent accumulations of earthy gypsum are found, but one mile south of the estuary known as Khor Makta'a Tubii, and through which at most conditions of the tide one's donkeys carry one on the direct route from Manáma to Rifa'a, a yellow shelly limestone with strings of gypsum is exposed which is no doubt Eocene.

Walking towards the south-east, the cliffs die away. Limestones containing numerous flints are found *in situ* overlying a soft saliferous marl. The same juxtaposition is seen on the beach at Ras Sanad opposite the small island of Sitra, where low cliffs some 15 feet high bound the sea-shore dipping slightly to the south. The flint concretions here are the largest I have seen in Bahrain, forming in some places continuous masses some 4 feet long. It is not unlikely that these flint beds correspond to the flint horizon of Jebel Dukhán.

South of this is Jebel Hisai. This is a line of hills forming perpendicular cliffs 40 feet high, between which and the fringes of the large flint-strewn plateau is a narrow sandy plain, only recently vacated by the sea. On the other side the ground slopes imperceptibly down to the date gardens north of the village of Farsiya. At the base of these cliffs is a soft yellow marl passing up into a rather harder white sandy marl. This is highly saliferous, and contains nodules and strings of brown limestone, which gradually shade up into a band varying in thickness within a short distance from 1 foot up to 20 feet, which is made up entirely of strings of a hard concretionary limestone containing numerous specimens of an *Echinolampas* belonging to the group of *Echinolampas sindensis*, *E. osiris*, and *E. alienus*, with *Terebellum* sp. Forming the summit is about 8 feet of a hard sandy non-fossiliferous limestone. Owing to the easily soluble nature of the underlying beds, these cliffs are deeply undercut, and the summit overhangs the base no less than 20 feet. It is, I think, clear that these beds must overlie those forming the main plateau, but the various sections described on the last page lead me to infer that the flint beds, at all events at the top, are quite local and inconstant.

Proceeding now to the opposite side of the island, facing the date gardens of Buri is another line of cliffs directly comparable to Jebel Hisai. Soft saliferous and gypsiferous marls form the base of the cliffs passing up into a distinctly nodular limestone. This line of hill stretches some distance northward and gradually dies away into the plain east of Al Bidia. Here outcrops of a hard limestone are occasionally met with, as well as accumulations of flints.

It only remains now to discuss the probable age of the Eocene rocks of Bahrain, and their correlation with other Eocene deposits.

The fossils hitherto determined are the following, of which the nummulites have been kindly examined by Mr. E. Vredenburg and the other fossils by myself:—

Nummulites beaumonti D'A.
Nummulites lævigatus Lam.

Porocidaris schmidelii Münst.
Schizaster mokattamensis P. deLoriol.
Echinolampas nov. sp.
Cidaris sp.
Echinolampas sp.
Terebellum sp.
Pecten sp.
Ostrea elegans var. *exogyroides* Mayer-Eymer.
Chama latecostata Bellardi.
Spondylus ægyptiacus Newton.

Nummulites beaumonti occurs in Baluchistan at the base of the upper Khirthar in the beds immediately overlying the zones of *N. gizehensis* var. *obtusa*, and Mr. Vredenburg remarks that the Egyptian form seems to occupy a similar horizon respectively to the zone of the *N. gizehensis* type in the Mokattam series.

Nummulites lævigatus Lam. has its maximum frequency in the upper beds of the lower Khirthar or in the passage beds between the lower and upper Khirthar. The Bahrain form is extremely depressed and papery, and Mr. E. Vredenburg compares it with *Nummulites Defrancei*.

Of the other forms *Porocidaris schmidelii* and *Ostrea elegans* var. *exogyroides* are common fossils in the Mokattam series of Egypt.

Schizaster mokattamensis is found both in the Libyan and also in the Mokattam.

The *Echinolampas*, which is the most common fossil in Jebal Hisai, is a new species, but belongs to the group of which *E. osiris* (*Desor.*) P. de Loriol, *E. sindensis* D'.A. & H., and *E. alienus* Bittner belong.

Echinolampas osiris is found in the lower Mokattam of Egypt; *E. alienus* occurs in the strata of San Giovanni Ilarione in Northern Italy, which Professor Sacco classes as Parisian, while *E. sindensis* belongs to the Khirthar division of the Indian Eocene.

We may therefore assign the Bahrain series to the middle Lutetian: it corresponds to some portion, probably the lower, of the

Mokattam series in Egypt which may be correlated with the base of the Khirthar in India.

2. Miliolitic Formation.

This is seen in two localities in the island of Bahrain, where the general character of the formation differs in no respect from that of the similar deposit found so frequently throughout the Gulf. It consists chiefly of foraminiferal tests encrusted with calcite along with a few sand grains. The stratification and the mode of occurrence possess, however, certain features of interest which I have not observed elsewhere. The first place in which the miliolite appears is in the deepest portion of the old river channel mentioned on page 116, on the Eocene plateau 3 miles west of Rifa'a Ar Jibliá. Its thickness here is no more than 3 feet, and it covers only a small area near the origin of the channel. It contains at its base angular fragments of the underlying limestone and flints. It is evidently false bedded as the planes of stratification are horizontal on one side of the channel and are dipping 10° towards the centre on the other.

In the second locality the miliolite is much thicker and more widely spread, but its mode of occurrence is directly comparable to that of Rifa'a Ar Jibliá. It lies along the bottom and sides of a rather deep and steep walled ravine on the northern flank of Jebel Dukhán. At the top of the ravine there is a cave in the limestone, right into the mouth of which the deposit dips down at an angle of as much as 20° abutting directly on a perpendicular wall of limestone near by.

Both of these deposits must occur at approximately the same elevation above the present sea level, namely, 200 feet, and both of them appear to have been subjected to a certain amount of denudation.

The false bedding and peculiar occurrence of the miliolite in Bahrain added to the evidence derived from its lithological structure leaves no doubt that it is a compacted wind deposit originally accumulated in sheltered places where it was secure from further movement by aërial currents. The question is referred to in the paragraph on the miliolitic deposits of the Gulf on page 55. It was probably laid down prior to the period when the central depression in Bahrain

was the site of a salt lake, since there is evidence that elsewhere in the Gulf it was formed previously to the recent littoral conglomerates. Hence we may consider it as Pleistocene.

3. Sub-recent Deposits.

The flat portions of the island bordering the coast, especially to the north of the island and including the whole area which is under date cultivation, are of sub-recent age. Behind Manáma are low shelves of a shelly conglomerate containing recent species of mollusca, and elsewhere are sands amidst which outcrops of the Eocene limestone appear, the more frequently as one draws near the edges of the plateau. Near the village of Al Bidia, are high mounds of wind-accumulated sand, quite loose and uncompacted.

Portions of this area have evidently been only quite recently vacated by the sea. Between Jebel Hisai and the Eocene plateau are numerous marine shells still retaining much of their original colouration, while near Nuwaidrat are such immense accumulations of Potamides that one is almost led to think that the sea still comes up there to-day, in spite of the assurance of the villagers to the contrary. In many such places large deposits of earthy gypsum occur. (See page 159.) Observations of a similar nature have been made within the great central depression. Fresh looking marine shells are found here and there testifying to the existence of a lake which was more or less connected with the sea through the narrow outlet near Sakhir. The line of cliffs affords in many places a beautiful example of a feature which has been produced by the action of the water as it has sunk by successive stages away from the land. A perfect series of terraces exists almost everywhere, shown in plate X, being clearly the remains of old beaches. The sudden drops are in most cases undercut. The deposit which has been previously formed has in almost every case been removed by the sea when it rested on the next lower level, or at all events the material with which the terraces are covered is not to be distinguished from ordinary aërial soil crop. At the last resting place of the sea only has the evidence of sedimentation been

preserved. Here in many places a soft sandy deposit has been left. This is particularly observed near the bitumen deposit where it is consolidated into a brittle sandstone containing recent marine shells.

The depression itself was produced at a period long prior to that at which a lake occupied it, and its formation doubtless commenced from the time when the Eocene deposits were first raised above the sea. The structure and nature of the rocks lent itself to the production of a hollow of this kind, namely, a dome containing a soft easily weathered rock intercalated between two hard limestones. The rainfall in those remote times must have far exceeded what it is to-day to have produced the ravines of Jebel Dukhán and the river channels on the plateau as well as the rugged torrent bed at Sakhir, which seems to have drained this basin.

The basin then was there previously and all that the lacustrine conditions have done was to modify the outlines, possibly to accentuate the indentations and complete the severance of the hills and promontories now isolated from the main mass.

A similar structure has already been noticed as existing at the northern edge of the plateau facing towards Manáma (page 118).

The smaller islands are in all cases of sub-recent formation. In Jiddi and Umm Nahsan coral reefs which I take to be of sub-recent age have been raised some 50 feet above sea level. This formation is being deeply undermined by the sea to-day, which gradually cuts beneath the limestone cliffs, which give way when their weight is more than the cohesion of the rock can support. In this way strewn at the foot of the cliffs in the island of Jiddi are huge blocks often measuring as much as 10 feet each way. As I have found no shells in this formation I cannot be quite certain as to the age of the rock.

A few brief words will suffice to summarize the probable geological history of Bahrain. Subsequent to Eocene times it was gradually raised above the sea and much of the formation denuded as it rose. The main features of the island as we now see it—the great central depression, the scarped cliffs and the plateau—were completed during interval, which, as we have no evidence of Miocene and Pliocene

deposits, may have continued into the Pleistocene. The miliolite is to be assigned to the close of this period, which was followed by a subsidence which let the sea into the central depression. A gradual elevation in sub-recent times has formed the Rifa'a terraces, and raised the littoral conglomerates, and this movement is probably being continued to-day.

One other point deserves to be mentioned in connection with the Bahrain islands; this is the prevalence of artesian freshwater springs to which the northern portion of the island owes its fertility. They have been mentioned by various writers, amongst whom may be mentioned Whish (14), Carter (12), Bent (27), Zwemer (34). The largest of them is situated at Adári. Here a plentiful supply of water is continually gushing forth, forming a limpid pool, whence the water is led in all directions to irrigate the date gardens. The temperature of this water is about 80° F. The soluble matter in the water is as much as ·028 per cent., of which 60·7 per cent. is due to sodium chloride. It is evident therefore that it must be rather brackish to the taste and in fact not generally drunk. Those who can afford it, and the Europeans generally, obtain their drinking water from Hanaini which lies in the plain just beneath the fort of Rifa'a. Other wells providing good water exist at Rifa'a itself, and in the south of the island. Many wells have been dug in the town of Manáma itself, of which some provide brackish water and a few sweet water. Amongst the latter is the well which has lately been sunk at the American Mission Hospital.

Springs exist in the islands of Sitra and Nabbi Salih, and in other places also. It is quite usual for springs to arise from beneath the sea. Of these many are situated on reefs which are exposed at low water, and from several of these the inhabitants of Moharraq obtain their drinking water. Carter relates how H. M. S. *Mahi* supplied herself with 700 gallons of good sweet water from a spring beneath the sea some 10 miles north-west of Manáma, by putting down a hose pipe.

It is certain that these great supplies of water are of artesian origin and are derived from the elevated country in the interior of

Arabia and the highlands of Nejd where it is likely that the rainfall is fairly large. This view is supported by the information supplied by Zwemer and others that on the adjoining mainland of Arabia, in Al Katif and Hasa, warm freshwater springs of a similar character to those in Bahrain are very abundant.

In Bahrain itself it appears that the water-bearing stratum lies beneath the limestones and marls of Jebel Dukhán. Wells sunk anywhere throughout the island down to this level obtain a plentiful supply of water, in spite of the often barren, uninviting character of the surface. In the north of the island, however, where the syncline probably brings these water-bearing strata to the surface, there is a regular set of springs.

It is remarkable that round Manáma the water supplied by various wells differs in character, which can only be accounted for by assuming that the water traverses more or less regular channels underground, and the water in any well is either brackish or sweet as the channel which supplies it has traversed saliferous strata or the reverse.

CHAPTER VI.

QISHM ISLAND.

Qishm, the largest island in the Persian Gulf, lies near its entrance, and in shape is long and narrow, being 60 miles long with an average breadth of about 8. The island for the most part is barren in the extreme. Low flat-topped hills belonging to the highest or *Pecten vasseli* division of the Fars series, rarely attaining an elevation of more than 4 or 500 feet and often less than that, spread throughout the island. The hilly country is broken up by perfectly flat plains which run up as narrow tongues into the hills or separate individual portions as islands from the main hilly mass. The whole presents an appearance of having been carved out by the sea, which has within recent times retired from the topmost levels, exactly as has been observed in Bahrain island. Here, too, terraces have been left at various levels, in many cases covered with sand, which is probably the remains of

a sub-recent beach deposit. These beach deposits are often slightly tilted. The phenomenon is not so striking or conspicuous, however, as is the case in Bahrain.

The highest point on the island, Kish Kuh, lies in the midst of an outcrop of the Hormuz series some 30 square miles in area. The hills on the south-eastern portion of the island are entirely covered by blown sand, which seen from the sea gives a pale buff colour to the whole of it. This blown sand, even on the tops of the hills, is several feet thick, and below the sheltered cliffs on the north side has accumulated to depths of 20 feet or more. This sand is interesting as exhibiting the recurrence of the same conditions which probably produced much of the so-called "miliolite."

At the eastern end of the island near the town of Qishm the Fars beds are well exposed, attaining a thickness of some 500 feet. The dip is never more than 5° and is often practically horizontal. The beds seem to roll about slightly, though the general direction of the dip in the eastern half of the island seems to be south-easterly. They consist of white indurated marl with fossiliferous bands containing—

Chlamys (*Aequipecten*) *bicknelli* Sacco.
Pecten (*Plagioctenium*) sp. *aff. ventricosus* Sowb.
Pecten vasseli Fuchs.
Ostrea sp. *aff. verleti* Desh.
Turritella sp.
Arca sp.
Placuna sp. cf. *placenta* L.
Cidaris sp.
Temnopleurus toreumaticus Ag. var.
Carcharias sp.

In one place near Deristán *Ostrea* sp. occurs in beds which are practically made up of them, so exceedingly numerous are they. The lowest beds seen are rather bluish clays with a few bands of plastic clay, the whole traversed by numerous veins of gypsum, one to three inches thick, intersecting one another at every angle.

Resting somewhat irregularly on the Fars clays is the typical miliolite deposit, a sandy foraminiferal oolite. In places this is several feet thick, in others there is very little of it, and it often passes into what is nothing more than a consolidated sand. The miliolite was found at the highest levels, that is to say, at an elevation of nearly 500 feet. But the most remarkable feature is that the miliolitic deposit is covered by a sub-recent littoral concrete containing numerous pebbles and shells. This appears to form the flat table-like summits of the hills with unvarying constancy in this part of the island, but the same deposit is found at several different levels as we descend to the sea, until finally it forms a low cliff some 6 or 8 feet high dipping into the water. These conglomerates are often slightly tilted.

These deposits seem to tell a fairly clear story of the history of the island. It is evident that since the topmost *Pecten vasseli* beds have been deposited, the land was elevated, it may have been to a very slight extent, but at all events sufficient to allow a quantity of drift sand to be deposited. The presence of beds of regular sand with the miliolite seems to indicate that the land did not stand far above the sea. At all events the presence of " miliolite " here is interesting as showing that very similar factors to these which exist to-day were at work in this area also in Pleistocene and probably Pliocene times. The large quantities of drift sand show that desert conditions prevailed in the neighbourhood. In order that a littoral conglomerate may have been deposited on the miliolite it was necessary that a second sinking of the land must have taken place ; but after that in recent times a gradual elevation seems to have continued until finally the concrete that was formed at sea level is now found 500 feet above it. None of these movements have been very great and can scarcely have amounted to more than mere minor oscillations.

As has been said above, the characters of the beds and the appearance of the landscape as detailed above for the eastern end of Qishm are true for the greater portion of the island, though I saw no accumulations of recent drift sand except on the hills in the south-eastern part of the island. In the eastern portion of the island are

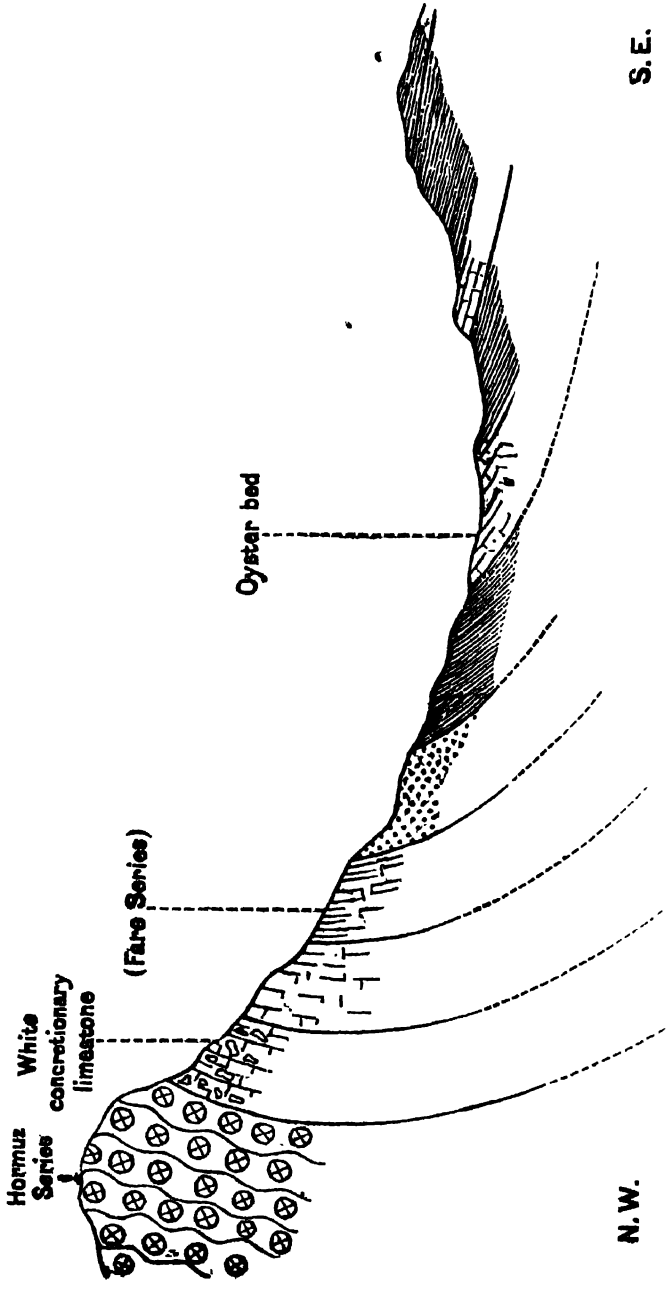

Fig. 6.—Sketch Section at Namakdán, Qishm Island.

no dips greater than 10°, the direction of dips which I have recorned being E., N.E., S.E., E.N.E.,E.S.E., W.S.W.

On arriving at the portion of the island where the rocks of the Hormuz series are exposed, a considerable amount of disturbance has taken place.

The Hormuz series stretches some 5 miles along the coast and extends inland for about the same distance, thus occupying an area of about 25 square miles. In this formation the island attains its greatest elevation, the summit of Kish Kuh being 1,300 feet. The accompanying section (Fig. 6) near Namakdán exhibits the nature of the boundary between the Hormuz series and the Fars beds. Within two hundred yards the dip of the Fars beds increases from 10° to vertical and finally becomes reversed, so that at the actual boundary an inverted sequence obtains. The total thickness of beds here exposed is about 600 feet. The basal beds exposed are a rather hard, pure white limestone with a band of yellow nodules identical with the Henjám rock. Traces of the red conglomerates of the latter island are also present here. Other beds exposed above this are loose crumbly uncompacted sandstones, greyish marls and clays with abundant gypsum veins. Shelly beds are seen here and there, amongst them the oyster bed observed further to the east.

The Fars beds overlie the dark red volcanic tuff; this is fresh and undecomposed at the boundary, but the great mass of the hills which I saw consisted merely of the bright red earth arising from its decomposition, with great masses of salt everywhere, and permeated by gypsum, while scattered over the surface are abundant specular iron ore and dolomite crystals just as in the other places where this formation is represented. It was impossible where I saw it to detect the original structure of the hills.

Salt is quarried here to a large extent and the product is the purest obtained in the Persian Gulf. The locality is known under the name of Namakdán. Further to the east, about 3 miles inland from the small village of Salak, some naphtha springs arise from another small outcrop of the Hormuz series.

On the western side of the Hormuz rocks the Fars marls again continue. Basidu itself is built on a ledge of sub-recent littoral concrete.

CHAPTER VII.

HORMUZ ISLAND.

The island of Hormuz lies at the very entrance to the Gulf just outside the port of Bandar Abbás and is about 5 miles long by 4 broad.

It would be hard to find any place presenting a more singular appearance than do these barren salt hills which cover nearly the whole of the island. They form an absolutely confused irregular mass of low hills, which do not as a rule attain a much greater elevation than two or three hundred feet, although one or two peaks in the centre of the island rise to 700 feet. They are cut up by an endless succession of valleys, ravines, and large cavities caused by the underground solution of the salt and the consequent falling in of the surface. They present every imaginable colour of the spectrum in addition to the dazzling white hills of salt or jasper and the coal black limestone. From their midst some feeble streams thread their winding way down to the northern shore, from whose waters crystallize out as they go, both on the surface of the water and on the banks of the stream, a thick deposit of salt through which the stream cuts a narrow channel. Its waters are a brilliant red from the red iron oxide either held in suspension or transmitting its colour through the clear water from the thick precipitate that coats the stream bed. To an imaginative eye it might be a river of blood bound fast in a wintry mantle of snow and ice.

The hills are absolutely devoid of vegetation, although to the north of the island, where there is a level strip of about 1 mile in breadth, some trees of *Zizyphus jujuba* are seen, while there are several low plants of a xerophytic type. In striking contrast to the scene of desolation behind are the ruins of the old

Portuguese fort of Hormuz,—less of a contrast now perhaps, in its ruined state, except in so far as it is suggestive of a time when this corner of the earth's surface was the scene of a commerce, a power and a magnificence, so much at variance with the dreary, waterless, broiling character of its surroundings. As it is, the spirit of mediævalism breathes from every buttressed bastion, from the arches of the chapel, from the columns of the courtyard, from the deep groined dungeons beneath.

Blanford chose this island to give its name to the formation, and not unfitly so, as there is little rock of any other age exposed here, and the characteristic rocks of the series are almost all exposed within its limits. Still the general character of the formation is the same wherever it is met with and makes it impossible to mistake it even at great distances.

The level portion of the island to the north consists of a platform of horizontally-bedded, sub-recent littoral conglomerate hardly ever elevated more than 10 or 15 feet above the sea and crowded with recent shells. On all other sides of the island the hills of the sal formation dip steeply down into the sea leaving no beach. Both the volcanic beds as well as the salt beds and sedimentaries are plainly dipping at about 50° to 60° S.W. or W., but over a great portion of the island the underlying rocks are concealed by a reddish earth which contains some carbonate of lime, large amounts of gypsum, impregnating the whole mass, and crystals of hæmatite (specular-iron-ore) scattered throughout. The colour is of course due to the hæmatitic red oxide of iron. Large deposits of this exist in one or two places in the island, pure enough to be of commercial value, for which they have been mined for many years. (See page 157.)

A buff grey limestone, with bands of chert, contains large crystals of iron pyrites. This mineral is also found in other rocks in the island, while sulphur is found in small quantity either aggregated in pockets or scattered through the rock.

It is possible that the gypsum may have arisen by chemical change in original calcareous beds. The pyrites is evidently a secondary

product produced by crystallization from water. This would very readily oxidize to sulphate, which, reacting with the calcium carbonate, would give rise to gypsum and iron oxide, both of which as we see are finely scattered through the mass. I incline to the idea that the whole of the gypsum in this series is secondary, although the sulphurous vapours which originated this cycle of change were very probably connected with the lava flows which seem to have alternated with periods of sedimentation.

Pyrite crystals are also found in a rock ($\frac{19}{362}$) which appears to be a much decomposed rhyolite with secondary calcite.

The red tuff, which has generally weathered away entirely, losing its identity in the vast mass of red gypsiferous earth, sometimes occurs in a less decomposed condition, and is seen to consist of a fine-grained andesitic ash containing numerous bombs of volcanic rock, also very fine grained, and free from glassy matter, while throughout are abundant crystals of dark-red secondary calcite and hæmatite.

The highest peaks in the island which are conspicuous from a distance by their dazzling whiteness consist of a pure white jasper.

The salt occurs in beds as much as 2 feet thick, but is exceedingly impure. It makes up as much as half the entire formation. Sedimentaries are not so evident, but grits, shales, and limestones are found in thin beds. All of these contain either hæmatite or pyrites.

CHAPTER VIII.

HENJÁM ISLAND.

The small island of Henjám lies close to the south of Qishm separated therefrom by a channel little over a mile in breadth but 80 feet deep, affording a safe anchorage. Henjám has a maximum length and breadth of 6½ and 3 miles, respectively, and its highest ground, which is not far from the telegraph station at the extreme north of the island, is only 350 feet. The formations represented are the

Hormuz series, the *Pecten vasseli* or coast beds of the Fars series, miliolitic formation and sub-recent littoral concrete, and a small outcrop which is provisionally assigned to the same series as the plutonic igneous series of 'Omán.

The Hormuz beds crop out in the centre of the island rather discontinuously from beneath all the newer formations. In a large cave some 40 feet of the deep red volcanic ash are exposed. At the base regular thin banded layers of salt, sulphur, and red tuff containing hæmatite are seen, the whole producing a richly diversified scheme of colouring. They appear to be dipping steeply. Above this are rather decomposed beds of volcanic ash passing from a red rock in which aqueous sediments are apparently hardly represented into a yellow bed containing pebbles. This passes up again into the deep red volcanic tuff.

Elsewhere, overlying the red volcanic tuff, is a curious rock, which in its present condition is a buff coloured jasper, honeycombed by numerous cellular spaces, which in an unweathered state are filled up with a sort of earth containing pale blue crystals. The earth is very soft and in exposed surfaces of the rock has all been eliminated leaving the cavities in the jasper empty. It seems that this earth represents the remnants of a volcanic rock of which the greater portion has been silicified.

A higher bed in the series is a rhyolite similar to that met in Hormuz and elsewhere.

The rock of this series that is met with most frequently in Henjám is the red tuff.

Standing quite by itself about 2 miles south-west of the telegraph station near the sea-shore is the only other type of igneous rock found in the island. It is a somewhat altered quartz diorite containing hornblende, tremolite, quartz, plagioclase, orthoclase, epidote, sphene, and chlorite. The felspar and hornblende are largely segregated in portions of the exposure. This isolated outcrop covers an area of about 800 square feet and rises to a height of 40 feet above the general level. The dip is some 35° N.N.E. Any idea of its belonging

to the Hormuz series may be dismissed, as the typical Hormuz lavas and tuffs are exposed at such comparatively short distances away from it as to preclude the possibility of any connection between them and a plutonic rock such as this. Filling up various cracks and holes in the quartz diorite is a hardened clay with specular-iron fragments, belonging to the conglomerate at the base of the *Pecten vasseli* beds and to be mentioned hereafter. This rock bears a distinct resemblance to diorites met with on the mainland opposite, between Khamir and Bostanah, which I have elsewhere (pages 106 and 110) given my reasons for considering as belonging to the serpentine igneous series of 'Omán. Provisionally, therefore, we may have no hesitation in considering this Henjám rock as an isolated outcrop of the serpentine series, which must have been completely covered by Hormuz lavas, ash beds, and sediments. These were denuded away, probably during a portion of the Eocene and Miocene periods, leaving it again exposed, to be again covered by Fars sediments in the Upper Miocene. It may be mentioned that boulders of a similar diorite occur on the beach some distance away, doubtless derived from this or from a neighbouring outcrop.

The coast division of the Fars series is well developed in Henjám to a thickness of some 270 feet. At the base is a conglomerate containing pebbles of igneous rock, numerous fragments of specular-iron-ore, and red tuffs, the whole enclosed in a very fine-grained compact calcareous matrix, which seems to have been deposited as a very fine intangible clay. The basal portions of this are of a deep red colour, and it is clear that all the materials of which it is composed were derived from the Hormuz rocks. It is found resting both against the red ash bed of the latter and against the above described dioritic outcrop. It runs out into the sea dipping 6°, and a recent deposit is in course of formation on it.

It contains numerous casts of organisms amongst which are—

Brissus sp. *aff. oblongus* Wright.

Temnopleurus sp. *aff. hardwickii* A. Ag.

Temnopleurus toreumaticus Ag. var.

Cypræa sp.
Cidaris sp.

This red conglomerate is perhaps 10 feet or so thick, and it shades up into a yellow shelly conglomerate, almost equally hard and compact, enclosing numerous pebbles of trachyte and specular-iron-ore, and this passes up into a calcareous clay with trachyte pebbles here and there, and veined with gypsum, and containing calcareous nodules and strings. In places the deposit seems to pass laterally into a softer pure white limestone in which a new species of *Lovenia* is very frequent, along with two species of *Cidaris* and their peculiar shaped spines and also a *Metalia*. This rock is chiefly exposed about 2½ miles south-south-east of the telegraph station and passes up into a blue marl. At the base of this occur numerous concretions and nodules, which are generally of a somewhat elongated or cylindrical shape, are of great size, often attaining a length of some 3 feet and 2 feet in diameter and weighing a quarter of a ton, and have been locally known as the petrified date palms of Henjám. These weather out from the softer marls and stand up against them. A magnificent section of this bluish marl is exposed with some interbedded buff-coloured argillaceous sandstone, which passes into a shelly deposit, above which is blue clay again.

Unconformably overlying this on the cliff is a deposit of miliolite, here white and containing small shell fragments. It is about 30 feet thick here and forms a good building stone.

The whole is capped by a sub-recent coarse shell conglomerate, which being more compact than the miliolite has weathered more slowly; consequently the wearing away of the miliolite has left umbrella-like projections of the concrete, which are irregular in proportion as the original miliolite surface formed uneven lumps and hillocks, before the deposition of the littoral conglomerate on it. In time the weight of the overhanging masses of conglomerate brings them crashing down, and the ground beneath the cliff is strewn with huge, curiously-shaped boulders of the conglomerate with attached

miliolite which go on weathering below until a perfect mushroom shape is attained.

The following is a complete descending section of the rocks exposed hereabouts :—

Sub-recent littoral conglomerate	8 feet.
Miliolitic deposit	30 „
Pale blue, rather sandy clay	50 „
Shelly grit	30 „
Argillaceous sandstone	15 „
Blue clay veined with gypsum and with large concretions at base	130 „
Pure white nodular limestone	20 „
Yellow shelly conglomerate	6 „
Red conglomerate	10 „

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The miliolite is of a precisely similar character to that found in Qishm. Not only does it rest high up on the Fars cliffs at a height of over 300 feet above sea level, but is spread over the whole island to a large extent at various elevations almost down to sea level. It rests directly on a rhyolite in the Hormuz series, and on rocks of different horizons in the Fars series. Finally, at Rghail at the south-western end of the island it lies quite unconformably on a set of Fars beds dipping as much as 10° (Fig. 7).

It is quite plain therefore that considerable denudation of the Fars rocks must have taken place, and they probably formed a land surface throughout the Pliocene and possibly Pleistocene during which time the miliolitic deposit was in the process of being accumulated by the wind. That all of it was derived from a shallow water or beach deposit is evident, and subsequent sifting by the wind removed the lighter portions of the beach deposit to their present position. (See page 55.)

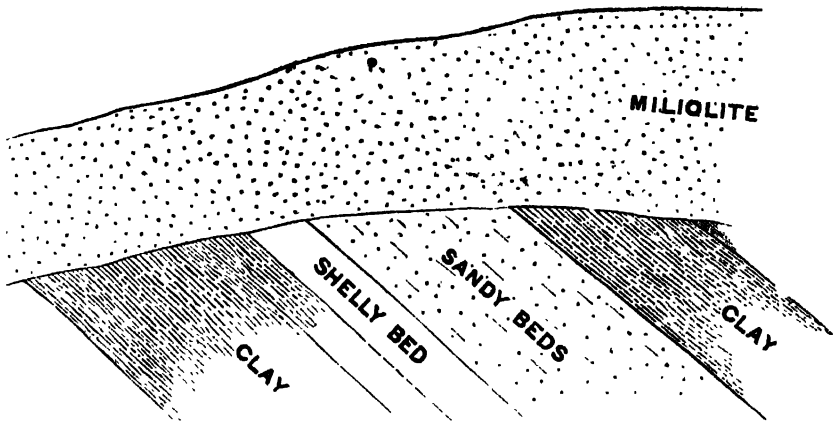

Fig. 7.—Miliolite resting unconformably on Fars series at Rghail in Henjam I.

The sub-recent conglomerate is found as in Qishm in some places directly overlying the miliolite, in others resting directly on Fars sediments or on rocks of the Hormuz series as it was to be expected that the miliolite from its mode of accumulation would be rather irregularly distributed.

CHAPTER IX.

BU MUSA ISLAND.

The island of Bu Musa is about 2½ miles long by 2 broad. One peak rises to an elevation of 360 feet, but most of the rest of the island is flat.

Geologically it consists almost entirely of rocks of the Hormuz series.

Near the sea on the south-eastern side there is a thick bed of red iron oxide, which is worked to some extent and shipped to India. There are only a few huts on the island inhabited by the one or two Arabs who are engaged in digging out the oxide. This red ochre deposit forms part of the regular red tuff of this series, and these beds are overlain by a purple trachyte, the whole forming a sharp

anticlinal fold, of which the beds are dipping as much as 40° in either direction. Not very far away extensive beds of gypsum occur, associated with the red tuff. Specular-iron-ore also exists. Salt, however, appears to be absent in Bu Musa. Sulphur is said to be found in small quantities.

The high peak consists entirely of trachyte. On its south-eastern side are some low hills of a dazzling white jasper having a pink tinge in places and containing crystalline quartz.

Hills of trachyte to the north of the peak are dipping 60° N.-W. In this rock sticking up in several places in beds about 6 inches thick and looking as if interbedded with the volcanics is a shelly conglomeratic grit as shown in the sketch in Fig. 8. It would seem that during the submergence of the island sandy sediments had been washed into the bedding planes of the lava, and this rock has withstood denudation longer than they.

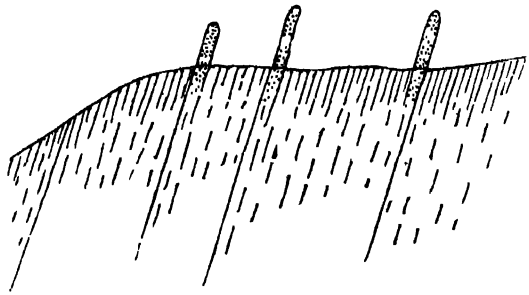

Fig. 8.—Sandstone bands projecting from a volcanic lava, in the cracks of which they were originally deposited. Bu Musa Island.

Here and there fringing the volcanic rocks, especially on the eastern side, are some sandy clays and grits, probably belonging to the Fars series. They are dipping about 3° and contain shell fragments and a species of *Echinodiscus*. They are hardly more than 20 feet thick and are overlain by a clearly recent or sub-recent littoral concrete.

CHAPTER X.

DAIYINAH ISLAND.

This is one of the numerous small islands lying in the southern portion of the Persian Gulf off the coast of Arabia between the peninsula of Qatar and the Trucial coast. It is 1½ miles long by ½ mile broad, and no part of it rises more than 8 feet out of the water. Except on the coast nothing is to be seen except sand or sandy soil covered with a red leaved succulent salsolaceous herb. A small depression in the middle is quite devoid of vegetation and seems at some recent date to have been a marsh or lagoon.

In many places a horizontally-bedded pebbly grit runs down into the sea. The pebbles are for the most part limestone, and I found coral and shell fragments in one spot. It seems to shade into the miliolitic deposit.

At the north end of Daiyínah are several rocky small islets, some of which are more or less connected with the main island by low sand spits covered at high water. These islets rise to 10 feet above sea level and consist of well-bedded limestone of a dark reddish tinge, in many places flaky or fissile and sometimes showing signs of contortion. It contains no trace whatever of any fossil. It seems to be the remnant of a partially denuded anticlinal fold striking north-west and south-east and dipping 25° S.W. and then bending sharply over to the north-east and becoming vertical. There seems little doubt that this limestone is an outlier of the great 'Omán series.

A coarse conglomerate composed mainly of fragments of the limestone overlies or abuts on portions of the limestone. This pebbly conglomerate has been deposited in the joints of the limestone where it is still seen.

A true miliolite has been laid down quite close right up against the limestone in positions which emphasize its resemblance to a wind deposit. In one place the miliolite forms a 6 feet cliff.

There is a curious sort of rock which seems to pass into miliolite consisting of large loosely compacted grains which have a truly oolite structure. With these are fragments of shells and echinoid spines. This rock is probably *in situ* in the original place where it was formed.

It is noteworthy that no representative of the Hormuz series occurs on Daiyínah. Yet we are by no means out of its area of deposit. It is found on Hálúl island to the north and on Dalmah to the south, while the small island of Arzánáh only 12 miles away to the south-east is reported by Carter to contain volcanic rock.

We have a choice of the following alternatives. Was the Hormuz series deposited on Daiyinah and subsequently removed by denudation, or was it never deposited ?

Judging by its almost universal presence in all these islands, the former seems unlikely, while on the other hand the existence of the older limestone here would point to this being a portion of an elevated area in Hormuz times.

CHAPTER XI.

HÁLÚL ISLAND.

The island of Hálúl lies about 70 miles due north of Daiyinah island and is separated from the southern group of islands, of which Daiyínah is a member, by a considerable distance. Its size is about 1½ miles long by ¾ mile broad.

On the south-eastern side, near the anchorage, are cliffs of sub-recent shelly concrete some 15 or 20 feet high, and these are found again in places on the western side of the island ; with this exception, however, the only formation represented throughout it is the Hormuz series. In this ordinary sedimentaries are well developed to an extent that I have not elsewhere seen in this series. Outcrops

of grey flaky limestone are everywhere common, interbedded with thick deposits of reddish gypsum and red tufaceous earth. I saw some fairly large and workable beds of red ochre. I found no salt or sulphur here, but specular-iron-ore, and very pure calcite crystals abound in places. On the western side, which is very rocky, fine sections of all these beds are exposed on the sea-shore. There is a greyish trachyte which has beautiful green crystals of epidote and gypsum mixed, developed in the joint planes. The dip of all these beds is very high as invariably seems to be the case with this series, though the direction of dip varies considerably. I found a small outcrop of more massive limestone, and also patches of black limestone. All alike were, however, absolutely unfossiliferous.

CHAPTER XII.

OTHER GULF ISLANDS.

I shall now briefly mention the other islands in the Gulf, the majority of which I have not myself seen, but on whose geology we have information from Carter or others.

Lárak lies immediately south of Bandar Abbás and is only 5 miles distant from the eastern corner of Qishm. It is 5 miles long by 4 broad, and rises to a height of 350 feet. Its rugged and craggy appearance and its red or variegated colouring, so characteristic of the Hormuz rocks, leave no doubt that the whole, or at all events almost the whole, of the island consists of rocks of that series. Carter mentions the presence of large quantities of micaceous hæmatite, but salt does not appear to be present.

The **Quoins** and the **Masandam islets** are entirely of the black limestone, in this case probably Triassic, belonging to the 'Omán series.

The **Greater Tunb** is 2 miles long by 2 broad, and rises 165 feet above the sea.

The **Lesser Tunb** is a mere rock a mile long and a few hundred yards broad, projecting out of the sea to a height of 116 feet. The island was visited by Blanford and by myself. A white argillaceous limestone belonging to the Fars series dips into the sea on the edge of the coast. This is capped by recent littoral concrete, of which most of the island consists. Miliolite also appears to be present, while at the south-west corner there is a small outcrop of the Hormuz rock.

Farúr is 3 miles long by 2½ broad, and in it are several peaks attaining an elevation of about 460 feet. In appearance it is an exact replica of Lárak, and, like it, may be assigned to the Hormuz series.

Sirri is about the same size as Farúr, but is only 50 feet high. According to Carter it contains the Hormuz volcanic rocks with micaceous hæmatite, gypsum, salt and sulphur, and a shelly deposit which he compares to that capping the cliffs at Qishm and which is therefore probably recent or sub-recent.

Sir Bu Na'air lies 45 miles south-south-west from Sirri, is 2½ miles long by 2 broad, possesses an elevation of 240 feet, and according to Carter contains volcanic rock and red ferruginous gypsum. We may therefore conclude that the Hormuz series is represented here.

Qais is a long low-lying island close against the Persian coast west of Lingah. It is 8 miles long by 4 broad, and from Carter's observations one may assume that it consists of sub-recent conglomerate with possibly true miliolite.

Hindarábi lies somewhat further to the west than Qais, is 4 miles long by 2 broad and 100 feet high. It consists of the same rocks as Qais.

Shaikh Shu'aib, still more to the west than Hindarábi, is 13 miles long by 2½ broad and stands up 130 feet out of the sea. The same remarks apply to its geology that have been made about Qais and Hindarábi.

Zirkoh, 2½ miles long by 1½ broad with an elevation of 540 feet, according to Carter consists of Hormuz rocks. We may conclude from Carter's observations that sub-recent littoral concrete and miliolite are also present.

Dás, 1½ miles long by ½ mile broad and an elevation of 145 feet, contains Hormuz rocks, but according to Carter no miliolite.

Qarnain, 1¼ miles long by ¼ mile broad and elevated 190 feet, Carter makes the same observation about this as Dás.

Arzánáh, 2 miles long by 1 broad and 200 feet high, consists, according to Carter, of Hormuz volcanic rocks with a sub-recent deposit, possibly including true miliolite.

Dalmah, 5 miles long by 3 broad and attaining an elevation of 244 feet, is evidently in the main of Hormuz rocks. I have myself seen specimens of micaceous hæmatite brought thence by Dr. Zwemer, and Carter has made the same observation also noting the presence of sub-recent sedimentary deposits.

Khárag is about 35 miles north-west of Bushehr, is 4 miles long by 2 broad and rises to 284 feet above sea level. Blanford visited the island and wrote a brief description of its geology. He also collected several fossils from some whitish grey beds of fine argillaceous limestone. These beds apparently agree precisely in lithological characters with those in Henjám.

The islands of **Farsi, 'Arabi, Qŕan, and Herguz** are all fairly near together, more towards the Arabian side of the Gulf, and about 80 miles south of Khárag. They are all mere rocks, standing up no more than a few feet above sea level, and from Carter's observations seem to consist of sub-recent littoral concrete. Near Farsi apparently bituminous springs exist beneath the sea, as Captain Constable records his ship having passed through a sea covered with an oily substance emitting a strong smell of naphtha.

Kubbar and **Qaru** are also mere low-lying rocks lying off Koweit, whose geological composition is similar to that of the last-mentioned group of islands. Between these two islands Captain Constable's ship passed through another floating tract of naphtha.

Part III.—Economic Geology of the Persian Gulf Region.

The present chapter deals with such minerals of economic importance as are known to occur in the region. It will be seen that Southern Persia and the Gulf region do not present as favourable a field for prospecting operations as Northern Persia seems to. Petroleum alone seems to offer any promise of great financial success, and the ultimate issue of the work which is being carried on in regard to it, remains at present quite doubtful. It must, however, be remembered that most of the Arabian coast is still unknown and valuable economic products may yet await discovery there.

The minerals or rocks of economic value which I have come across in this region, and which I shall deal with individually in turn, are the following :—

Petroleum and asphalt.
Sulphur.
Iron.
Iron oxide (red ochre).
Steatite.
Alum.
Gypsum and anhydrite.
Salt (sodium chloride).
Building stones.

Petroleum and Asphalt.

There can be no question of the abundance throughout the area under consideration of what may be called petroleum manifestations. The existence of these has led to several attempts to obtain oil by boring, but none of these have been successful in any marked degree, and the majority have been failures. These manifestations take the form of—

1. Springs emitting sulphuretted hydrogen gas, and depositing bitumen,

2. Paroxysmal outbursts beneath the sea as a result of which particles of floating bitumen are to be seen in greater or less quantity covering the water around the spot.
3. Deposits of asphalt or bitumen.

Appearances of this kind are met with in a broad belt extending along the valleys of the Euphrates and Tigris in a north-west and south-east direction down the Persian Gulf and into Baluchistan. It seems to be an almost inevitable conclusion that the bituminous manifestations throughout this belt are connected with and due to the same cause or causes. We may examine the two theories, which have been advanced to account for the origin of petroleum, with the object of determining which of the two is most likely to furnish us with the cause to which the petroleum of this area is due.

The two theories are briefly —

1. That it was formed *in situ* from organic matter.
2. That it has a deep-seated origin and was formed chemically.

If the petroleum were confined to a single formation the first of these two theories would suffice. The facts of the case, however, are that we find petroleum in the Miocene rocks of the Fars series, in the Eocene of Bahrain and Persia, in the Cretaceous rocks of Khamir, Qishm and the Persian Gulf, and if we look at the closely adjoining and very similar area of the Caucasus, we shall find it in rocks ranging in age from the Jurassic up to the Miocene. It does not seem likely that the peculiar conditions admittedly required for the production of petroleum according to this theory can have been so constantly present in this area in past geological ages. Again, although bitumen occurs in rocks of such diverse ages, yet it is most abundant at two special horizons, that of the base of the Fars and in the Hormuz series. In both of these it is associated with gypsum, salt, and sulphur. The occurrence in two totally different formations of petroleum in association with gypsum, salt, and sulphur cannot be a

fortuitous one, more especially as the same concourse of mineral products has been noticed in many other parts of the world. In association with the Hormuz series we also have volcanic rocks, and although there are none in the Fars, it seems unavoidable to my mind to conclude that in both cases the formation of the petroleum is directly due to volcanic action. It may be mentioned that the peculiar mode of occurrence of the salt in the Fars series at Kamârij leads one to suppose that it was an eruptive mass.

But in any case without dogmatizing on the question of its origin we must conclude that the petroleum is contemporaneous with the gypsum beds in which it is stored. Hence it will be useless to look for it in younger rocks such as the Bakhtiyári series. If we accept the theory of its origin *in situ*, it will also be hopeless to bore down into the older rocks in search of it.

But it is because I wish to admit the possibility of its being stored in these older rocks, *provided that they afford a suitable reservoir*, that I have stated my opinion of a volcanic origin for it.

My examination of the older Nummulitic rocks of Persia did not, however, lead me to regard them as in any way favourable for the storage of large quantities of petroleum. They are for the most part massive limestones, at all events in the area I am considering.

At Báku the petroleum beds appear to be of Oligocene age, but here the porosity of the dolomitized limestone has enabled these beds to store considerable quantities of oil.

Exploitable petroleum in this part of Persia is therefore to be looked for in the lowest beds of the Fars series, which in their lithological characters would afford as favourable a reservoir as could be desired. According to the recognized theories of petroleum storage one must also select localities, where the strata have a low anticlinal structure, in which the rocks overlying the bituminous beds have not been denuded. These conditions are only partially fulfilled at the base of the low range of hills, where the petroleum springs of Kasr-i-Shirin, Shushtar, Rámuz, Behbahán, and Dáliki are situated, in fact in all the localities where borings for petroleum have

ever been conducted. I am quite unable to say how far my remarks apply to different points along the foot of this range, but at Kasr-i-Shirin, in the Rámuz plain, and at Dáliki the beds are not very greatly disturbed, but form a fairly gentle anticlinal flexure. It is also apparent that in all these places the basal beds of the Fars series lie quite near the surface, and most of them in fact are exhibited as a scarped face on the hill side. Under these circumstances it is not wonderful that such petroleum as I consider is disseminated throughout the formation should in virtue of the laws of hydrostatic pressure find an outlet at the foot of these hills. Also, since the greater portion of the formation has been laid bare for ages untold, it is also evident that most of the petroleum that existed in it once has been wasted. As the whole thickness of strata in which the petroleum exists is probably not very great (perhaps 500 feet), any curtailment of it is a serious matter, apart from the removal of the impermeable cover, which preserves the oil.

I cannot presume to say whether anywhere along this line of the anticline the overlying beds of the series are undenuded, but in such a place, if it exists, there will be more likelihood of obtaining large supplies of petroleum rather than where there are conspicuous surface "shows." For I cannot share M. de Morgan's opinion expressed in the *Annales des Mines*, 9th ser., vol. I, p. 227, 1892, and in *Mission Scientifique en Perse*, vol. III, Pt. 1, pp. 63-71, that there is a great subterranean source, which feeds the surface reservoir. I cannot quite realize whether M. de Morgan assumes (1) the continuous formation of petroleum at the present day, or (2) a reservoir accumulated in past times in or below the Eocene rocks.

The first I do not consider likely,—not by any means because I think it inherently improbable that petroleum is in course of formation in the world to-day, but because the invariable association of petroleum with these rocks and its absence in the Bakhtiyári grits leads to the conclusion that all the petroleum in the Fars series is of the same age.

If it is the second possibility to which M. de Morgan inclines, then

as I have already said, I cannot consider the Eocene rocks as a sufficiently favourable reservoir.

That the supplies of Shushtar though small are unexhausted is proved by the constant annual yield of petroleum, but I wish to enforce the point that that supply would not be increased by deeper borings, because one would then be below the petroliferous rocks.

I am unaware what rocks were penetrated by the boring at Dáliki, but as the gypsum beds are exposed at the surface it is quite likely that they reached the Eocene rocks. In any case the boring was unsuccessful.

That the petroleum is spread throughout this set of beds is shown by its presence at Om Gheir near Basra, Benaid al Qar near Koweit, Hit on the lower Euphrates, Kerkuk on the Hamrine, and Hamam Ali on the Tigris near Nimrud. The covering of all these Miocene deposits by the Mesopotamian alluvium will render it quite impossible to predict the chances of success of any boring. The attempt by the D'Arcy Company was unsuccessful. I do not know what geological conditions they found there, so that I cannot say how far they support my views on the accumulations of petroleum in the area.

In all other places, where I have seen the lower beds of the Fars series, they have been so folded, contorted, and denuded, as to entirely preclude any possibility of finding any petroleum supplies left in them.

The "shows" of oil at Ahmedi and Rudun north of Bandar Abbás probably arise in the Fars series, but I have no certain information with regard to them.

To consider now the other period of petroleum formation, namely, that of the Hormuz series. The rocks in this formation have been invariably so much folded and denuded, previous to the deposition of the tertiary beds, that it seems hopeless to attempt operations here. The naphtha springs at Salak in the island of Qishm arise from this formation, which forms a small inlier amongst the later Fars (Miocene) rocks. The sulphur springs at Khamir, which, however, seem destitute of bitumen, also occur in an inlier of the Hormuz series, in this instance bounded by sandstones and limestones of Eocene age.

With the exception of the asphalt, the only petroleum manifestations which it remains to consider are the apparently paroxysmal outbursts of bituminous matter in the Gulf. One of these occurs some 10 to 15 miles north of Hálúl island.

There seems some reason to think that it arises from the Hormuz series. Another area has been referred to by Carter between the small islands of Kubbar (29° 4′; 48° 30′) and Qaru (28° 49′; 48° 48′) and still another 12 miles north-north-east of the small island of Farsi (28° 0′; 50° 10′).

As the Hormuz volcanic area does not appear to have extended so far to the north-west, it is reasonable to suppose that these two last-mentioned springs arise from the Fars series, as indeed may be the case with the one north of Hálúl. Their periodicity is perhaps to be ascribed to the same causes as the similar phenomenon in various mud volcanoes. We have no data to guide us in expressing an opinion as to these submarine petroleum "shows" except that any which arise in the Hormuz series may be at once dismissed without further thought for the reasons stated above. In any case, when we consider the extremely doubtful importance of the petroleum "shows" in other parts of the area, it does not seem worth while to consider seriously any proposition for conducting boring operations in expensive sites.

The only deposit of asphalt or bitumen, which I examined,—if I except the unimportant bed of slightly bituminous limestone which I found in the Bakhtiyáris,—was that in the island of Bahrain. I shall therefore proceed to state the result of my examination of the deposit in question.

The asphalt deposit of Bahrain is situtated about 3 miles south-south-east of Jebel Dukhán, the name given to the clump of limestone peaks in the centre of the island, and is some 17 miles distant from the town of Manáma. The road lying between is for the most part flat and does not present any particular difficulties to transport on donkeys.

The asphalt beds are situated just beyond the termination of the rocky limestone formation of which Jebel Dukhán consists, and which

is the oldest in the island. They are probably of Middle Eocene age. From this point a plain begins, only recently vacated by the sea, which has left traces of its presence in numerous shelly sandstones and other recent alluvial deposits which cover up to a great extent the Eocene rocks overlying the Jebel Dukhán beds, and containing the bitumen. These rocks are for the most part soft marls containing a greater or less amount of sand. At Ain El Qar, which is the name under which the bitumen locality is known to the Arabs, the beds are all dipping some 10° to the south-east. About ¼ mile away on the plain still newer beds crop out in some low ridges; these are the characteristic soft Nummulitic limestones of which the circle of cliffs in Bahrain consists. These are also dipping to the south-east some 6°.

The diagrammatic section on page 114 (Fig. 5) will make this description clearer.

It will be apparent therefore that the strata are disposed in a low anticlinal dome, of which the crest lies in or near Jebel Dukhán. The topmost beds have been denuded and are only represented by the asphalt-bearing strata and by the low hills mentioned above.

Before proceeding to discuss the possibilities of petroleum being found in the area it would be well to deal with the asphalt deposit. The accompanying sketch-map (Plate XIII) on the scale of 110 feet to the inch shows the relation of the asphalt deposit and the excavations made, to the surrounding hills. The original well was dug by the Arabs and shows the most valuable portion of the deposit which has been brought to light. Six other pits were dug by Mr. J. C. Gaskin, the contents of which I was able to examine carefully, while I myself dug another pit and deepened the original Arab excavation with the idea of showing the general line taken by the deposit. Below a depth of about 30 feet there was great difficulty experienced in keeping the water out.

In the original well (No. 1), there is exposed a great mass of bituminous limestone of the same quality as that of which an analysis was made n the laboratory of the Imperial Institute, by Professor W. R. Dunstan, M.A., F.R.S.

About 2 cwt. of the asphalt rock were received, which was fairly sampled, and should therefore be quite representative of the deposit in the central well. The result of this analysis was as follows :—

Moisture	0·59 per cent.
Volatile matter	17·47 „
Fixed carbon	5·30 „
Ash	76·63 „

The amount of bitumen contained in the asphalt rock was determined by extraction first with acetone to remove the liquid bituminous matter (petrolene) and subsequently with chloroform which dissolves out the solid bitumen (asphaltene) :—

Matter soluble in acetone (petrolene)	10·47 per cent.
Matter soluble in chloroform (asphaltene)	7·20 „
Total bituminous matter	17·67

The composition of the ash was as follows :—

Silica	SiO_2	66·24
Alumina	Al_2O_3	9·54
Ferric oxide	Fe_2O_3	2·31
Magnesia	MgO	2·22
Lime	CaO	15·78
Soda	Na_2O	2·20
Potash	K_2O	1·65

The material was reported commercially to be of excellent quality and compare favourably with the La Brea deposit of Trinidad.

By dilution with about 75 per cent. of its weight of powdered limestone it could be converted by heat and pressure into a substance quite suitable for paving purposes.

This deposit is met with at a depth of 34 feet, and in the actual well the base of the deposit is reached on the south-west side at about

38 feet; the deposit seems, however, to continue much deeper to the east-north-east and the direction of the main vein probably becomes vertical; at the same time the diameter of the vein diminishes.

The following are the details of the strata met with in this well:—

1 to 20...Sand and alluvial deposits.

21 to 22...Sand tinged with bituminous detrital material.

22 to 34 ..Sandy marl.

34 to 38...Sandy limestone impregnated with bitumen forming good asphalt.

I have some grounds for thinking that the bituminous matter met with between 21 and 22 has been derived from the subsequent erosion of the deposit.

Well No. 2—

1 to 26 ...Sand and alluvial deposit.

26 to 26¼...Sand slightly coloured with bituminous detrital matter.

26¼ to 31 ...Soft sandy marl with no traces of bitumen.

Well No. 3—

1 to 27 ...Sand and alluvial deposit.

27 to 27¾...Dark brown marl with some bituminous matter.

27¾ to 32 ...Sandy marl free from bitumen.

Well No. 4—

Sand and alluvial deposits with no traces of bituminous matter down to 33 feet.

Well No. 5—

1 to 22...Sand and alluvial deposits.

22 to 33...Bituminous marl of a brown colour.

33 to 34...Limestone with agglomerations of calcite crystals.

34 to 37...Soft chalky marl with brownish colouration.

37 to 44...Cherty limestone with bitumen contained in the joints.

Well No. 6—

1 to 24 ...Sand and alluvial deposit.

24 to 24¼...Sand slightly discoloured by bituminous detrital matter.

24¼ to 32 ...Sandy marl slightly discoloured by bitumen.
32 to 33 ...Marl containing no traces of bitumen.

Well No. 7—

1 to 24 ...Sand and alluvial deposit.
24 to 26½...Fairly hard brown asphaltic marl.
26½ to 33 ...Sandy marl slightly discoloured by bitumen.

Well No. 8—

1 to 21 ...Sand and alluvial deposits.
21 to —?...Hard compact grey limestone.

It seems probable that the bitumen occurs as a vein or pocket deposit which bears evident marks of having been intruded across the bedding planes of rocks of Eocene age, impregnating the loose marls and limestones, and so producing what we know as asphalt. The vein is of small dimensions and possibly ramifies exceedingly in the lower strata where the rocks are harder and more compact, but above has been able to spread out and permeate the more spongy arenaceous marls. The absence of any asphalt in well No. 6, and its marked occurrence in well No. 5, seem to indicate that it found its way by several distinct channels through the siliceous limestones up to the porous deposits. The main vein possibly proceeds vertically at some distance beneath the surface, but at all events from 40 feet beneath the surface it seems to follow a diagonal course in a north-east to south-west direction and at an angle to the surface of the ground. It is, I think, evident that such an intrusion did not occur subsequent to the laying down of the recent or sub-recent alluvial deposits, which cap the plain to a depth of 20 feet, because they show such a slight bituminous colouration. Moreover, the fragments of bituminous limestone, which occur in places above the bituminous deposit, indicate that it had been exposed prior to the sub-recent submergence, and was then covered up, as we now see it, by the recent deposits of this later stage. On account of the similarity of the Eocene sandy marls to the alluvial deposits it is naturally very difficult to say where the one ends and the other begins, but the essential facts in the history of the deposit seem to be as I have stated, and the intrusion may very likely

have been contemporaneous with the Lower Miocene stage of petroleum generation. With regard to the amount of asphalt present it seems likely that some one hundred and fifty tons or so of good asphalt might be dug out from the spot, which might contain from 10 to 17 per cent. of bitumen, while perhaps double that amount of inferior quality might be obtained. This would readily be taken by any dealers in such material for road-paving or other purposes. But the deposit need not be seriously considered in the light of its offering any scope for an export trade, although it would be a pity not to make some use of it locally.

Seeing that there is no evidence of faulting or unconformity one would be prepared to find other pockets of asphalt in the same formation in the plain, but there is no surface indication of such, and it would be impossible to point out a spot where excavations might be conducted with success.

I will now proceed to consider the bearing of this bitumen occurrence on the possibility of finding a petroleum supply in Bahrain. It is evident that terrestrial conditions, which were capable of producing this bitumen, were also capable of generating petroleum, possibly even in quantities quite disproportionate to the small asphalt deposit which I have just reported on.

The strata which overlie the Jebel Dukhán beds are admirably adapted lithologically for storing petroleum. There are fairly impervious rocks beneath these porous strata, and the flinty limestone overlying them is well adapted to form an impervious cover. If then an anticline existed, in which these beds and their cover were undenuded, one would be justified in advocating boring on the chance of meeting a valuable reservoir of petroleum. In the present instance, however, as I have already stated, not only the whole of the "cover" but also the whole of these porous beds have been removed from the anticline by the operation of atmospheric forces, so that any petroleum which ever existed in these beds must long ago have drained away.

There is of course a possibility that beneath the limestone which

now forms the topmost beds of the anticlinal crest there exists another porous stratum. As I have not seen any lower beds of the series than these limestones, and as Bahrain is the only place in the Gulf where the series is found, I cannot express an opinion on this point.

Sulphur.

The only two localities of any importance which I saw were the sulphur mines at Khamir, east of Lingah, and those at Bostanah, west of Lingah. In both cases the sulphur occurs finely disseminated throughout a white, dusty, decomposed rhyolite in association with abundant gypsum. Occasionally the sulphur is found in pockets of the size of a pomegranate, but these are by no means common. In both these places there are some 1,000,000 tons of the rotten rhyolite in sight, but as there is really so little sulphur actually diffused through the mass I do not consider that even under the most favourable conditions of working and extracting the sulphur, sufficient profit will be attained to compensate for the labour required in the process.

Several years ago these sulphur mines were worked in a primitive fashion. The material was dug out and piled up, to perhaps about the height of a man, over a sort of retort made of baked clay and sunk below the ground level. The retort is connected to a gutter leading out to the side of the heap. The whole heap is plastered over with gypsum as well as the receptacle into which the melted sulphur flows. Fire is set to it and the sulphur melts and flows down into the interior of the heap and out into the receptacle. It is allowed to stand for some time, until it has become sufficiently cool for all the sulphur to have condensed and solidified. At that time the mines were extensively worked and sulphur was even exported to India. But I gather in the first place that there were richer and larger veins in sight at that time, which paid for their extraction. This must have been the case to produce 60 to 90 thousand mans (of 9 lbs.) annually, which was what the output amounted to in 1865, according to Pelly (*Trans. Bomb. Geog. Soc.*, vol. xvii, p. 242, 1865). In the second place it

would seem that the troublesome customs duties have increased the cost of labour at the mines.

Within the last year they have again started to work the mines at Bostanah. The best quality of sulphur sells for 6 krans per man (of 9 lbs.), or about Rs. 13-8 per Indian maund, which speaks for itself, and the general value of the deposit may be gauged by the fact that in the coast markets of Persia it is cheaper to buy foreign sulphur than the native product. For many years the Persian grandee who farmed the mines demanded so large a sum that no one thought it worth while to take them ; but I imagine that recently he has preferred to be content with the small profits that might accrue by selling the sulphur in the interior of Persia, rather than allow the mines to stand idle.

The geology of the deposit will be found on page 104.

There are undoubtedly sulphur mines inland at the town of Hormuz and perhaps elsewhere, but I know nothing either of their geology or of the value of the deposits. Sulphur also occurs in connection with the salt deposits of Qishm and Hormuz islands, but is of no economic value. There are strong probabilities of its occurring also in some of the gypsum beds at the base of the Fars series, as I heard several reports of it though I saw none myself. In any case, however, the quantity would no doubt be too small to be of any material value.

Iron.

Iron is disseminated with unvarying constancy and in great purity throughout the Hormuz series, as hæmatite and as pyrites. It does not occur anywhere, however, in sufficient abundance to make it valuable economically, certainly not for export.

The igneous rocks and quartzites of 'Omán to the south-west of Muscat contain small quantities of iron scattered through them both as magnetite and hæmatite. The magnetic compass is noticeably deflected throughout the area, but here also there is not sufficient to make it profitable to work.

Iron oxide or red ochre occurs in large deposits in various islands in the Persian Gulf among the Hormuz series, resulting from the decomposition of the hæmatite. It is widely scattered through the gypsiferous or saline earth everywhere, but its association with these salts renders it less valuable as an article of commerce. In many places, however, it occurs in a more or less pure condition, and is dug out in large quantities and shipped to India for use as a pigment. The chief places where these pure deposits of red ochre are found are in the islands of Hormuz, Bu Musa and Hálul.

Steatite.

Steatitic clay is found in small quantities associated with Nummulitic rocks near Muscat, where it is dug out and used by the inhabitants of Matra for moulding pots.

Alum.

Alum is found in small quantities at one or two places on the Persian coast, of which Hamairan was the only one I saw. Apparently these deposits in this part of Persia are quite unimportant.

Gypsum.

There are few areas over which gypsum is so universally spread as in the Persian Gulf. It occurs in at least three different formations. Great beds of rock-gypsum are met with at the base of the Fars series. This is the massive variety and consists of very fine, almost microscopic crystals of gypsum mingled with a very small amount of earthy matter. It is often quite translucent and attains a high measure of purity. It weathers into the most fantastic shapes owing to the solution of portions of it by atmospheric water. Besides the beds of rock-gypsum, scattered throughout the clays are veins of pure selenite, which are obviously of secondary origin. Such veins are sometimes found traversing the beds of rock-gypsum. Throughout the whole of Persia and the Gulf it is universally used as a cementing material under the name of "gaj" (gutch), for which purpose it is admirably adapted,

producing a very lasting structure. Its softness is rather against its use for paving purposes, as it is constantly worn away under the feet. I am not aware that it is used for any other purpose in Persia. There seems no reason, however, why it should not be utilized for the manufacture of plaster of paris, or as a surface dressing in agriculture.

The beds of rock-gypsum in the Fars series vary in thickness from 3 up to 10 feet, and often succeed one another very rapidly with a very small thickness of intercalated clays or marls, bringing up the total thickness of gypsum in any one place to some 200 or 300 feet. These beds during the great orogenic period of folding, being soft and pliable, yielded readily to pressure and have frequently been folded over and over on themselves so that one often meets with almost continuous exposures of gypsum for a mile or more across the strike. This circumstance will tend to render even greater quantities of it available for working than would otherwise be the case. The gypsum beds are exposed at various places at the base of the first mountain range going inland from Bushehr, but probably not to the same extent as farther inland. Still where this range comes out to the coast, as is the case between Kangun and Naband, great quantities of gypsum can be won without much trouble and can be shipped without incurring the expense of a land journey.

This is still more the case at many places between Lingah and Bandar Abbás, where gypsum of great purity has only to be dug out on the sea-shore and dropped into the boats which are waiting for it alongside. Here the gypsum beds are vertical: therefore as there is no overburden to be removed, the labour of winning it is trifling so long as the gypsum which is above the plain of denudation lasts. For these reasons this is the most valuable of the various deposits of gypsum in the Persian Gulf.

Gypsum is also found throughout the Hormuz series, but it is in most places so mixed up with salt, red iron oxide, and earthy matter that it is much less valuable. The best deposits of gypsum in this

series that came under my notice were those of Bu Musa and Hálúl island, the former being particularly good.

One other occurrence of gypsum deserves mention. This is the deposit of earthy gypsum which has been produced in recent or sub-recent times as a result of the leaching of gypsum out of the older rocks and its deposition on the surface of the ground by the subsequent evaporation of the water. This has occurred to some extent in areas covered by the Hormuz series and has resulted in the production of a gypsiferous and saline soil, the gypsum of which is, however, invariably most impure.

But in several places in Bahrain earthy gypsum is found to a depth of several feet, of sufficient purity to be useful. This has been derived from the gypsum scattered through the underlying Eocene rocks. The chief locality for this kind of gypsum is the small island of Umm Nahsan, on the west side of Bahrain island. It can be dug out without any difficulty and is the source of all the gypsum used in Bahrain for building purposes. Other areas of less importance exist on the plain south of the date gardens of Belád El Kadim, and in the extreme south of the island.

Salt.

Salt is found widely scattered through the Hormuz series in almost unlimited quantity. The largest deposits of it occur in the island of Hormuz, where, however, it is slightly impure through the presence of red iron oxide. Before it can be offered as a commercial commodity it would have to be recrystallized. This process of recrystallization goes on in Hormuz naturally to some extent. A small perennial stream flows through the island, and along the banks of this the salt has crystallized,—to some considerable thickness in places. But it is not probable that water is obtainable in sufficient quantities to make it possible to carry on the process artificially on the spot. In the island of Qishm the salt attains a much greater degree of purity, and is quarried in the salt caves of Namakdán and exported to the amount of some 20,000 tons a year.

A very pure deposit of salt came under my notice at the base of the Fars series, at Kamárij on the Bushehr-Shiraz road about 100 miles from Bushehr. The overburden would, however, probably render it difficult to obtain.

Building Stone.

Of the harder and higher class building stones, the Nummulitic and Cretaceous *limestones* of Persia and the Carbo-Trias limestones of 'Omán and Masandam offer abundant material, whose value for the better kind of architectural work has been tested by their survival in the great buildings of antiquity. Of the softer building stones the Eocene limestones of 'Omán make an excellent freestone as also do the sub-recent coral limestones of the small island of Jiddi near Bahrain. The sub-recent littoral concrete which is met with throughout the Gulf is also extensively used for building; the town of Bushehr is entirely constructed of it. Some of the *sandstones* of the Bakhtiyári series, which are met with on the Kárún, make a handsome building stone, but much of it is not lasting.

Marble is not found in the area of the Persian Gulf, but some of the rocks of the 'Omán series would doubtless take a fine polish.

The *serpentine* rock of Muscat would, if needed, provide an admirable road-mending material.

Clays of excellent quality for brick-making occur in the Fars series, in the islands of Qishm and Henjám and on the Persian coast.

Sands are abundant on Qishm and on the Trucial coast.

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In this Memoir the Arabic K has been transliterated, in accordance with official usage, by the letter Q, so that place names beginning with an Arabic K will be found under Q.

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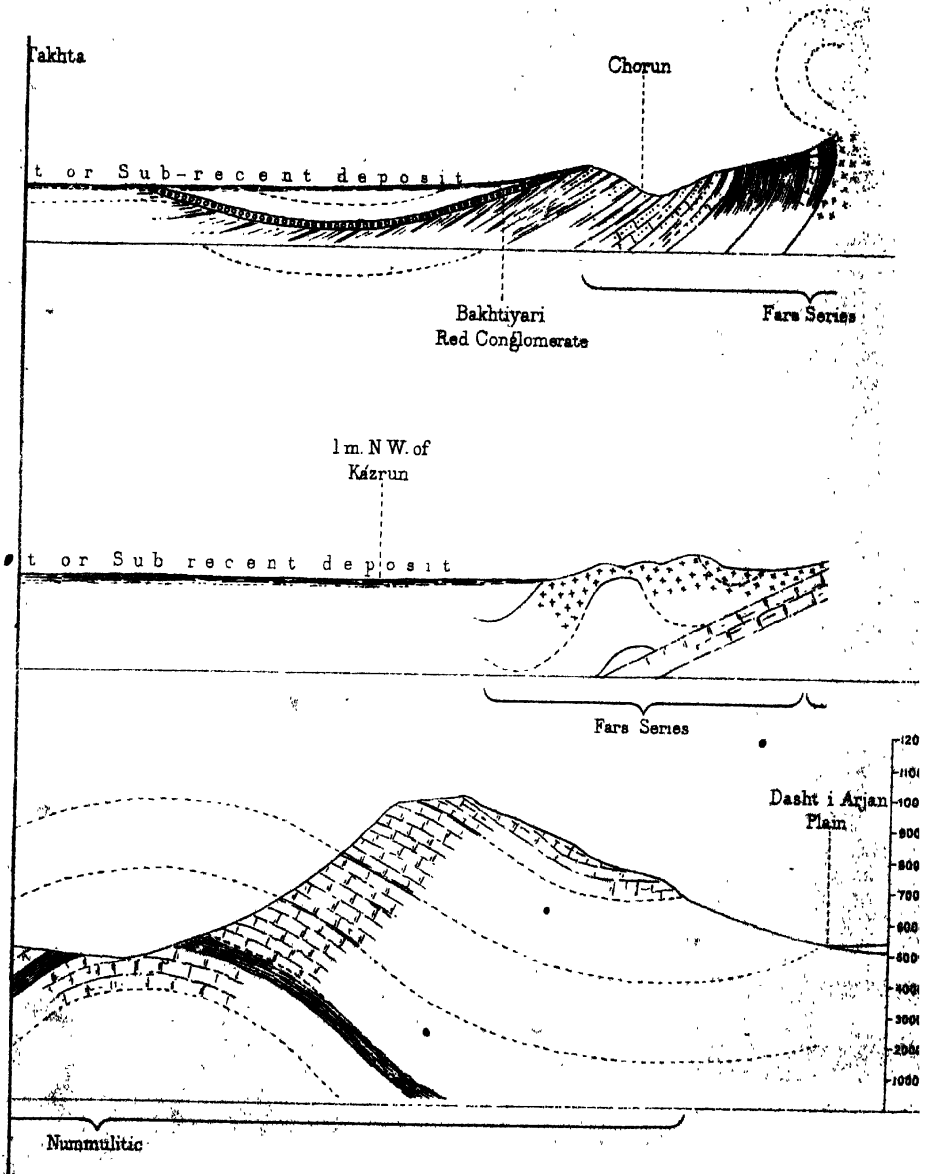

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